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United Nations Development Programme - UNDP

Project BRA/14/G31 - Renewable Biomass-base Production of Charcoal for the Steel Industry in Brazil

Charcoal Production Chains for the Steel Industry

Results of the Study on Charcoal Production Chains for the Steel Industry

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Summary

Results of the Study on Charcoal Production Chains for the Steel Industry

1. Introduction

The Project on Sustainable Renewable Biomass-based Production of Charcoal for the Steel Industry in Brazil (Sustainable Steel Industry Project) aims at fostering the development of a sustainable steel production chain of low emission of greenhouse effect gases (GEG). The project is implemented by the United Nations Development Programme (UNDP) and coordinated by the Ministry of Environment (MMA).

Following are the project participants:

- Ministry of Environment (MMA).
- Ministry of Industry, Foreign Trade and Services (MDIC).
- Ministry of Science, Technology, Innovations and Communications (MCTIC).
- Ministry of Agriculture, Livestock and Food Supply (MAPA).
- Minas Gerais State Government.

One of the expected outputs of the Sustainable Steel Production Project is to design a strategy to promote the use of sustainable charcoal to produce pig iron, ferroalloys and steel.

To outline that strategy the Sustainable Steel Industry Project hired consultancy services to develop several studies to update information about the use of charcoal in the steel industry, mainly focusing on the state of Minas Gerais.

One of the studies produced to the Steel Industry Project was named 'Charcoal Production Chains for the Steel Industry". The study was developed from October 2016 to June 2018 by this author, and resulted in four outputs:

1. Assessment of relevant methodologies for the analysis and quantification of the efficiency of charcoal production chains for the pig iron, ferroalloy and steel sector.
2. Analysis of the state-of-the-art of charcoal production chains for the pig iron, ferroalloy and steel sector.
3. Comparative analysis of the state-of-the-art technologies to produce charcoal for the pig iron, ferroalloy and steel sector.
4. Proposal to improve the sustainability and performance of the charcoal for the pig iron, ferroalloy and steel sector.

This publication named "Results of the Study on Charcoal Production Chains for the Steel Industry" summarizes the findings of the four aforementioned outputs[1] and was divided into the following sections:

1. Context - discloses brief considerations about the use of charcoal in steel industry and the carbonization process; details the charcoal production technologies; summarizes the remarks about the carbonization products and charcoal production in Minas Gerais; briefly describes the charcoal production chains.

2. Methodology of analysis to assess the charcoal production chains' efficiency, recording the author's proposal on selected methodologies to analyze and quantify the efficiency of charcoal production chains for the pig iron, ferroalloys and steel industries. Here, the charcoal production chains were evaluated based on the carbonization technology used by each of them, and comprises four analysis levels: technical, environmental, social and economic.

3. Diagnosis of the state-of-the-arts of production chains and carbonization technologies based on the findings of the specific analysis of the charcoal production chains for the pig iron, ferroalloys and steel industry. Analyses were developed considering the methodology proposed to evaluate the efficiency of the charcoal production chains.

4. Proposals to improve the performance of the renewable charcoal production for the pig iron, ferroalloy and steel industry in Brazil, mainly focusing on the state of Minas Gerais; the proposals recommend improvements to enhance the environmental, social and economic sustainability of the technologies, based on the findings of the diagnosis of the state-of-the-art of production chains and carbonization technologies.

5. Conclusion, in which the author presents specific considerations on the use of charcoal in the steel industry, mainly focusing on the state of Minas Gerais.

2. Context

2.1. Use of charcoal in the steel industry

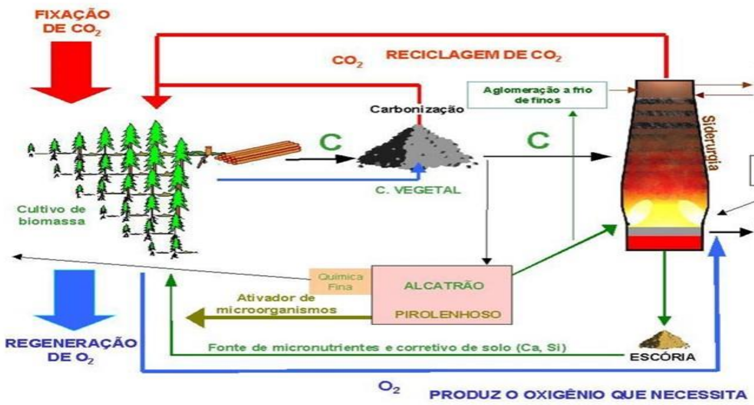
[1] The four outputs of this consultancy service are available at:
https://drive.google.com/open?id=1NVVVxZ7L3QIXVhH2FEZjmLJqE3Hfq2xk

The steel industry produces pig iron, ferroalloys and steel through a chemical reaction of iron ore thermal reduction.

Two inputs may be used as iron ore thermal-reducer to produce pig iron: the coke obtained from mineral coal and the charcoal produced from biomass (wood).

The use of charcoal entails the advantage of self-depuration as it is in today's era of Earth. Wood comes from living matter, reforestations, and the charcoal carbonization co-products (pyroligneous extratct and wood tar) can be reused, even as alternates to greenhouse effect emitters (SAMPAIO and LOPES, 2001).

Figure 1 - CO_2 recycling process in the charcoal-based production of pig iron.



Source: Sampaio and Lopes, 2001.

2.2. The carbonization process

Carbonization consists in heating the wood in a closed environment, i.e., absence of oxygen, until the thermal decomposition of its components: hemicellulose, cellulose and lignin[2].

The carbonization goal is to concentrate carbon (C), which is the main chemical element used in iron ore thermal reduction to produce pig iron.

[2] Hemicelluloses are literally "half cellulose", are polysaccharides. Jointly with cellulose, pectin and glycoprotein, it forms the cellular wall of vegetal cells. Cellulose is a long-chain polymer made up by one single monomer (glucose), classified as polysaccharide or carbohydrate. It is one of the main elements of the plants' cell walls (around 50% of the plant mass), in combination with lignin, with hemicellulose and pectin, and is not digestible for humans, being a dietetic fiber. Lignin is a complex organic polymer that gathers the cellulose fibers, increasing the vegetal cell wall rigidity and, jointly with cellulose, makes up the largest part of the wood of trees and shrubs. Information available at <https://pt.wikipedia.org>.

Because of that, the main indicator of charcoal quality for the steel industry is the Fixed Carbon Content (Density, Moisture, Generation of Fines and Ashes are other charcoal quality indicators).

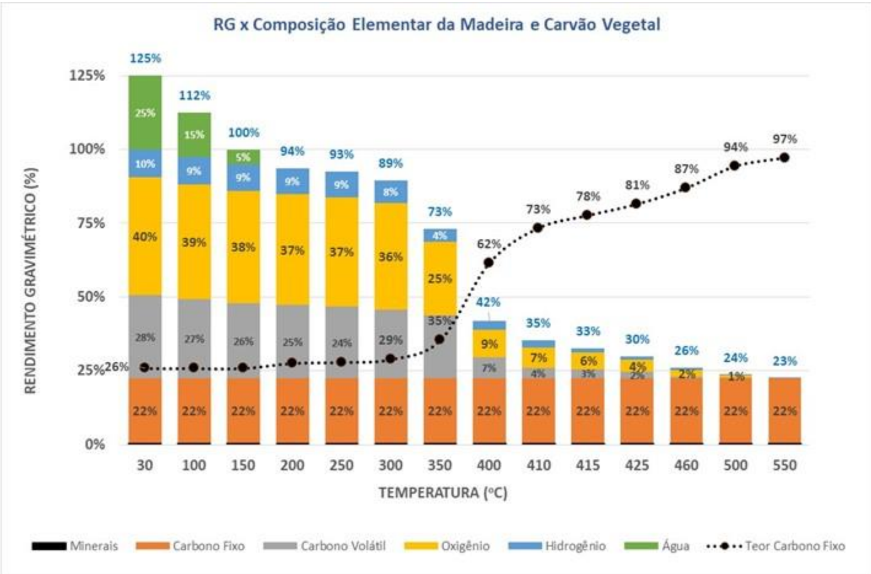
The closed environment where carbonization takes place is named kiln or reactor, and is the main component of a carbonization technology.

The main indicator of the carbonization oven efficiency, in turn, is the Gravimetric Yield (GY), i.e., the index of wood to charcoal conversion.

2.2.1. Relation between the Gravimetric Yield (GY) efficiency indicator and the charcoal quality indicator, Fixed Carbon Content

Figure 2 displays a schematic graph with data on the wood decomposition (RAAD, 2004).

Figure 2 - Elementary chemical composition of wood/charcoal at different carbonization stages (process temperatures), GY of the process and corresponding fixed carbon.



Source: Raad, 2004.

During the carbonization process the elementary carbon mass initially present in wood is around 50%. On the graph displayed in Figure 2 this mass is divided in two ways:

- During the carbonization process part of this elementary carbon mass will be released as carbon dioxide (CO_2), carbon monoxide (CO) and methane (CH_4) and other hydrocarbons (such as wood tar). The carbon found in those compounds was separated and named by the author as Volatile Carbon (gray bar) and initially calculated as 28%.

- Part of the elementary carbon mass will remain constant in the solid residue (charcoal) regardless the carbonization temperature (under atmospheric pressure), the so-called Fixed Carbon (orange bar).

It is worth mentioning that other elements such as oxygen (O) and hydrogen (H) are virtually volatile and are discharged together with the Volatile Carbon as the process temperature rises. Therefore, the solid residue percentage is the Gravimetric Yield (GY).

The curve of the fixed carbon percentage content (Figure 2) was obtained dividing the constant residual carbon mass (orange bar) and the total solid residue mass, charcoal (sum of the bars of hydrogen (H), oxygen (O), volatile carbon, fixed carbon and minerals) at the different temperatures of the process.

Typically, the fixed carbon concentration process during carbonization is the same in the masonry brick kilns technologies, different from metallic kilns that use burnt gases injected in kilns to supply the required energy rather than the partial burn of the wood in the oven (CGEE, 2015).

What makes the technologies different, in the technical light, is the geometry, dimension, productivity and capacity of controlling the process temperatures aiming at the highest GY possible, respecting the quality demanded by the final user (steel industry) regarding the Fixed Carbon Content.

A field survey carried out by this consultancy among different corporations working with pig iron independent production in Minas Gerais, approaching the desired chemical quality of the charcoal, found as follows:

- More than 90% of the consulted companies want fixed carbon ranging from 70% to 78%, but almost all of them get values from 78% to 88%.

There is a scientific explanation for what happens today in the industry’s charcoal production that supports the result of that survey:

- According to statistical surveys carried out during a study performed by the CGEE (2015), the estimated baseline for the average national GY was around 26%.

- With GY around 26%, the wood decomposition rate is much reduced and tends to values close to zero (Figure 2).

- The main indicator of carbonizers that visually operate the masonry brick kilns is the smoke discharged. By the moment of low gas flow they close the process. That is why the yield is low and fixed carbon contents are high.

- In kiln equipped with temperature controls the process can be concluded at periods of higher yield and, therefore, with lower fixed carbon contents.

- This consultancy confirmed some affirmations during the field survey with independent producers of pig iron and ferroalloys (Minasligas and Metalsider) and charcoal producers (Biocarbono) that use carbonization control systems.

2.3. Carbonization products

Gaseous and solid products result from the wood decomposition in the carbonization kiln.

The gaseous products resulting from wood carbon are divided into condensable and non-condensable.

Condensable gases are wood tar and pyroligneous extratct that can be reused to produce the so-called carbonization co-products.

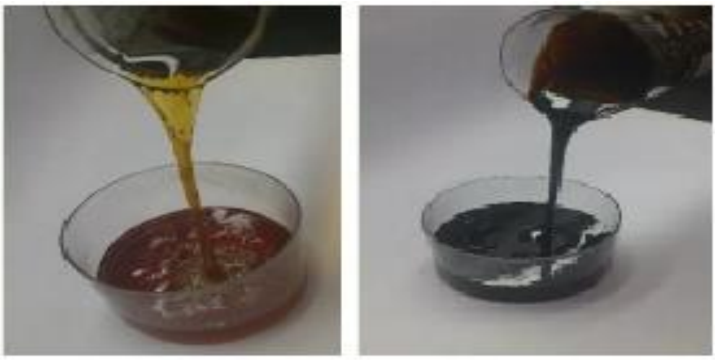
Non-condensable gases are the methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), in addition to nitrogen (N) (LOPES, 2010).

The charcoal is the solid product resulting from the biomass carbonization process (LOPES, 2010).

Figure 3 - Wood carbonization process

:Source Author's collection.

Figure 4 - Products obtained form the condensation of carbonization smokes: pyroligneous extratct and wood tar.



:Source Author’s collection.

2.4. Charcoal production in Minas Gerais

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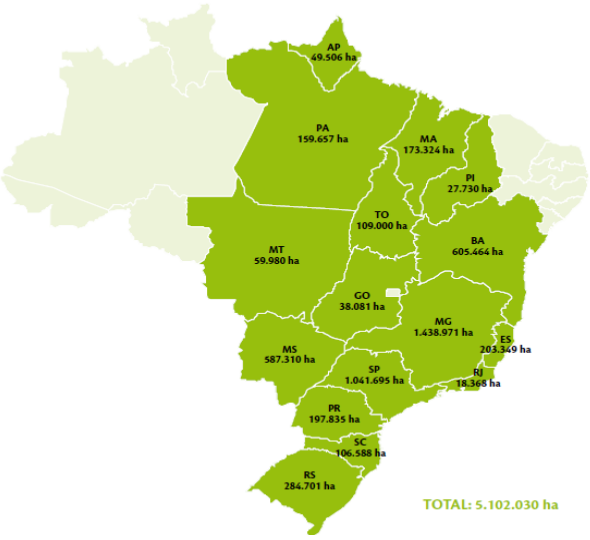
The most known and abundant wood to produce charcoal in Brazil, notably in Minas Gerais, comes from the planted eucalyptus forests. (IBGE, 2015).

Figure 5 - Eucalyptus forest massif.

:Source Author’s collection.

Brazil has about 5.1 million hectares (ha) of areas planted with eucalyptus, of which 1.3 million ha are in Minas Gerais (ABRAF, 2013 and SINDIFER, 2016). This qualifies the state as the biggest national producer, and justifies the focus of the Sustainable Steel Industry Project.

Figure 6 - Areas of eucalyptus planted forests in Brazil (*Eucaliptus* and *Pinus*).



Source: ABRAF, 2013.

In terms of planted areas in Minas Gerais, around half of it is intended for charcoal production for the steel industry. The sub-sectors of steel and pig iron producers are the largest consumers of the eucalyptus wood (SINDIFER, 2016).

Table 1 - Planted forests in Minas Gerais by production chain.

Steel Industry			**Forestry Products**			**Independent Production**		
Pig iron	Aço Integradas	Ferroligas	Processed wood	Cellulose	Wood panels	Use for energy	TIMO investors (*)	Others (**)
319,166	359,235	99,219	13,190	147,891	68,000	24,150	185,362	145,946
777,620			229,081			355,458		
1,362,159 ha								

Source: SINDIFER, 2016.

(*) TIMO – Timberland Investment Management Organization.

(**) Small and medium size investors, individuals and firms, rural producers, development of the State Forests Institute - IEF.

Planted forests and charcoal production can be found in several municipalities in Minas Gerais. The largest production sites are concentrated in the cities of Itamarandiba, João Pinheiro, Três Marias and Curvelo (IBGE, 2015).

Table 2 - Charcoal production (tons/year) by municipality and federative unit.

PROCEDÊNCIA DA BIOMASSA	MUNICÍPIOS PRODUTORES	UNIDADES DA FEDERAÇÃO				%
		MG	MA	MS	Outros	
CARVÃO VEGETAL DE FLORESTAS PLANTADAS (t/ano)	Municípios Diversos	1079308				24,1%
	Itamarandiba	928478				20,7%
	João Pinheiro	354906				7,9%
	Três Marias	272614				6,1%
	Curvelo	195944				4,4%
	Itacambira	150500				3,4%
	Buritizeiro	133212				3,0%
	Carbonita	129984				2,9%
	Lassance	126253				2,8%
	Olhos d'Água	111990				2,5%
	São João do Paraíso	83125				1,9%
	Lagoa Grande	82456				1,8%
	Grão Mogol	82232				1,8%
	Bocaiúva	80990				1,8%
	Felixlândia	75199				1,7%
	Taiobeiras	68084				1,5%
	Sen. Modestino G.	64500				1,4%
	Turmalina	61017				1,4%
	Bom Jardim		173477			3,9%
	Açailândia		161728			3,6%
	Ribas do Rio Pardo			62500		1,4%
	Total da Produção (t/ano)	**4080792**	**335205**	**62500**		100,0%
CARVÃO VEGETAL DE FLORESTAS NATIVAS	Região Norte/Nordeste				1393756	98,6%
	Região Central/Sudeste				20506	1,4%
	Total da Produção (t/ano)				**1414262**	100,0%

Source: IBGE, 2015.

2.5. Charcoal production chains

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Production chain can be defined as the set of consecutive stages through which different inputs pass by, are transformed and transferred (PROCHNICK, 2002).

In Minas Gerais, biomass is transformed into charcoal by:

- Independent charcoal producers.
- Independent pig iron producers
- Ferroalloy producers.
- Steel producers.

Independent charcoal producers are entrepreneurs who have or not own forests, and corporations associated to groups that invest in forestry activity. They supply charcoal mainly to independent pig iron producers, although they may complement the demand by steel and ferroalloy producers, as well.

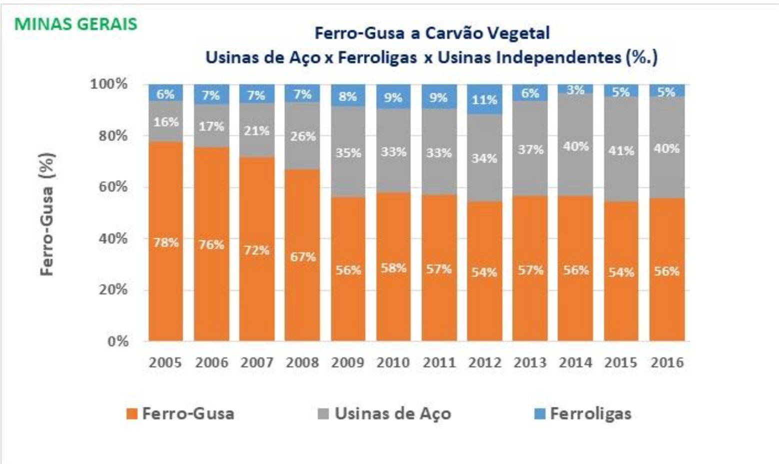
It is worth mentioning that most of the charcoal in Minas Gerais is produced by small independent producers, i.e., those operating plants with production capacity lower than 75,000 cubic meters of charcoal/year, equivalent to 15,000 tons/year (CGEE, 2015).

The independent producers of pig iron operate only the iron ore thermal reduction phase, and sell the pig iron to steel producers. In most cases, they purchase the charcoal to produce the pig iron from independent producers, around 55% of the input produced in Minas Gerais (Figure 7).

The ferroalloy producers also use charcoal to reduce iron ore. Unless exceptions, they produce the charcoal they use, equivalent to 5% of the state production today (Figure 7).

Steel producers operate the integrated mills, which are named this way because they perform the three phases of the steel production process: reduction, refinement and lamination. Generally, they are self-sufficient in terms of charcoal production. They consume 40% of the charcoal production in Minas Gerais (Figure 7).

Figure 7 - Percentage distribution of charcoal-based pig iron producers



Source: SINDIFER, 2015; AMS, 2012.

2.6. Charcoal production technologies

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The charcoal production technologies used by the steel industry in Minas Gerais can be pooled according to the material they are built of:

- Masonry brick kilns

- Metallic.
- Hybrid (masonry brick and metal).

Masonry technologies

- Circular non-mechanized masonry brick kilns (“*rabo-quente*”).
- Circular masonry brick kiln with mechanized discharge.
- Rectangular masonry brick kiln of small, medium and big size.

Metallic technologies

- Carboval.
- Rima Oven Container (FCR).
- Drying Pyrolys Cooling (DPC).
- Ondatec.

Hybrid technology

- Veredas system of charcoal and bio-oil production (Veredas).

The charcoal production technologies may come standard or be improved with peripherals to improve performance and acquire functionalities, such as increased gravimetric yield, reclaim of condensable gases for co-product or gases burn.

2.6.1. Masonry brick kiln technologies

The masonry technologies are represented by the circular masonry brick kiln with or without discharge and partial mechanization, and by the small, medium and big rectangular masonry brick kiln.

The non-mechanized circular masonry brick kiln (“*rabo-quente*”) are labor-intensive to load wood and unload charcoal, and are the most used in Brazil. It is estimated that about 50% of the charcoal production uses this model (CGEE, 2015).

Figure 8 - “*Rabo quente*” brick kiln

Source: AMS, 2017.

The circular masonry brick kiln with partial mechanization are a bigger version of the "*rabo-quente*". Wood is loaded manually, while charcoal is mechanically unloaded using loaders.

The circular masonry brick kiln with no or partial mechanization are the prevailing technologies for charcoal production in Minas Gerais, being found in all production chains. This kind of oven prevails among independent charcoal producers.

The circular masonry brick kilns are empirically conducted by the carbonizer based on the flow and color of the smoke from the oven. Conduction means to close or keep open the oven orifices and chimney, in order to control the entry of oxygen.

Figure 9 - Circular masonry brick kilns with partial mechanization.

Source: AMS, 2017.

The small, medium and big rectangular masonry brick kilns are fully mechanized and have higher wood processing capacity than the circular masonry brick kilns. The conduction of rectangular masonry brick kilns with no control of the carbonization process temperature is empirically performed by the carbonizer.

Figure 10 - Rectangular masonry brick kilns

Source: AMS, 2017.

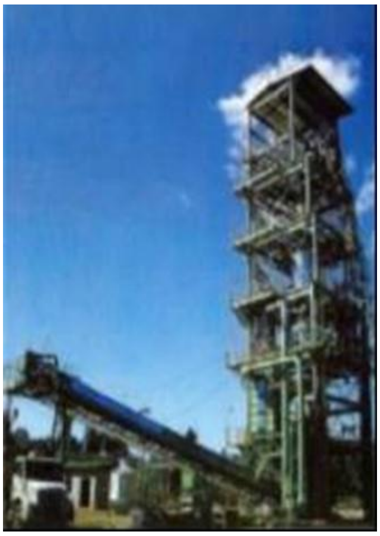
2.6.2. Metallic technologies

Carboval.

Carboval is a totally metallic technology, considered to be one of the most modern ones to produce charcoal. It uses the process smoke in a burner to supply the required energy to dry and carbonize the wood, in a continuous cycle.

Wood loading and charcoal unloading are mechanized.

Figure 11 - Carboval.



Source: AMS, 2017.

The Carboval technology comes standard with peripheral system to control the carbonization process temperature and gas burner. The technology emphasizes the maximum gravimetric yield possible, associated to the burn of gases for thermal use to dry wood and produce electric power.

RIMA Technology

The Rima container kiln (*Forno Container Rima* or FCR) is equipped with a system for forced suction of the gases resulting from the carbonization process. Part of the gases is used to conduct the carbonization process and the remaining part is burnt, and may be used to produce electric power.

Figure 12 - FCR.

Source: Author's collection.

Wood loading and charcoal unloading are mechanized.

The FCR technology comes standard with peripheral system to control the carbonization process temperature and gas burner. The technology emphasizes the maximum gravimetric yield possible, associated to the burn of gases for thermal use to dry wood and produce electric power.

The Carboval and FCR technologies are used by steel and ferroalloy producers, respectively.

DPC technology

The DPC (drying, pyrolisis, cooling) process is equipped with valve system to conduct the flow of gases resulting from the carbonization process.

Figure 13 - DPC technology

Source: Author's collection.

Wood loading and charcoal unloading are mechanized.

The DPC technology comes standard with peripheral system to control the carbonization process temperature and gases burner. The technology emphasizes the gravimetric yield.

ONDATEC technology

The Ondatec process employs microwaves as source of energy to the carbonization process.

Figure 14 - Ondatec technology

Source: Author's collection.

The production process is continuous and charcoal is unloaded in metallic containers, which can be directly conveyed to the final consumer or be transferred, through transshipment, to conventional trucks.

The Ondatec technology comes standard with peripheral system to control the carbonization process temperature and gases burner. The technology emphasizes the gravimetric yield.

The DPC and Ondatec brick kilns are not operational today in the charcoal production chain for steel production in Minas Gerais.

2.6.3. Hybrid technology

VEREDAS SYSTEM technology

The kiln of the Veredas System for charcoal and bio-oil production have brick masonry walls and removable metallic roof. They are interconnected one another to allow the transfer of gases that are partially burnt, thus contributing with the better efficiency of wood drying and carbonization.

Figure 15 - Veredas.

Source: Author's collection.

Wood loading and charcoal unloading are mechanized.

The Veredas technology comes standard with peripheral system to control the carbonization process temperature and gases condensation. The technology emphasizes the gravimetric yield associated to the condensation of gases to produce the carbonization co-products such as bio-oil.

It is the latest charcoal production technology. It is used by independent charcoal producers and independent pig iron producers.

3. Proposed methodology to evaluate the efficiency of the charcoal production chains

As mentioned in the introduction of this publication, the first stage of the study "Charcoal Production Chains for the Steel Industry" comprised the relevant methodologies to analyze and quantify the efficiency of charcoal production chains for the pig iron, ferroalloy and steel sector.

According to the author, the analysis and quantification of charcoal production chains' efficiency should concern the carbonization technology used by each of them, comprising four levels: technical, environmental, economic and social, as further detailed.

3.1. Technical analysis

In technical terms, it assessed the quantity and quality of the charcoal produced regarding Gravimetric Yield (GY) and Fixed Carbon Content.

3.1.1. Gravimetric Yield

The Gravimetric Yield (GY) of the carbonization process is the charcoal mass produced during carbonization divided by the wood mass used to produce charcoal, both on dry basis, i.e., "moisture-free" (UNFCCC, 2012).

The GY is the most relevant technical index in the carbonization process (CGEE, 2008). Its rise entails positive impact on the financial (CGEE, 2015) and environmental sustainability of the charcoal production technology, contributing to reduce the methane gas (CH_4) emissions (UNFCCC, 2012).

Base value: the higher the Gravimetric Yield, the better; the ideal range is from 30% to 40%. For any value in this range the Fixed Carbon Content reference should be between 70% and 80%.

3.1.2. Fixed Carbon Content

The fixed carbon found in the charcoal is responsible for the efficiency of the iron ore reduction process in the blast furnace. The higher the fixed carbon content, lower the charcoal consumption (BRITO, 1993; SANTOS, 2008; SANTOS *et al*., 2012; SEYE, 1998).

The fixed carbon content is limited by the charcoal mechanical strength. Contents ranging between 80% and 95% lead to lower mechanical strength. Therefore, the ideal fixed carbon content ranges from 70% to 80%.

Base value: between 70% and 80%.

3.2. Environmental analysis

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In environmental terms, the capacities of methane gas (CH_4) emission reduction and co-products reclaim presented by the carbonization technologies were evaluated.

3.2.1. Capacity of methane gas (CH_4) emission reduction

Carbonization produces charcoal and smokes made up by condensable and non-condensable gases. Non-condensable gases are the methane (CH_4) and carbon dioxide (CO_2), greenhouse effect gases, and the carbon monoxide (CO).

Base value: the higher the Gravimetric Yield, lower the methane gas emission.

3.2.2. Capacity of reclaiming co-products

The condensable gases generated during the carbonization process, when reclaimed, result in pyroligneous extract and wood tar (LOPES, 2010). These can be processed and transformed into bio-oil, alternate fuel for fossil-based oils and greenhouse effect gases emitters.

The financial feasibility of some technologies depends on the capacity of reclaiming co-products (CGEE, 2015) associated to the market potential for the resulting products.

Most of the carbonization plants that use masonry brick kilns in Minas Gerais miss a layout that allows effectively channeling condensable gases and the central positioning of the condenser.

The parallel layout of the carbonization plants is a barrier for condensation, due to the distance to be run by gases between the kilns' outlet and the condenser's inlet. The gases rich in pyroligneous extract and wood tar do not reach their destination. This results in low calorific value wood tar, with no quality to serve as raw material for the production of bio-oil to replace fossil-based oil.

In market development terms, the bio-oil has not yet been recognized as an alternate to the fossil-based oil.

Moreover, to transform the wood tar into bio-oil, the charcoal producer should endeavor to develop high-quality product and market. However, there are no quality standards to rule the production and sell of bio-oil in large scale.

Base value: none. It depends on the reclaim efficiency of the technology adopted, quality standard of the production and market development for the product.

3.3 - Social analysis

In social terms, the impact of the carbonization technology on social inclusion and income generation for the persons involved, in addition to the possibilities provided to reduce gender inequality, were evaluated.

In social terms, the state-of-the-art of the non-mechanized circular masonry brick kilns points out inclusion regarding job opportunities for male rural workers without formal education, including the illiterate ones (Dias et al. 2012).

It should be added that workers with some formal education, even if only fundamental level, unless exceptions, are not interested in working as kiln operator. This lack of interest has restricted the labor force to hold the function, mainly in Minas Gerais.

There is no gender insertion. Much happens because functions are considered more sensitive to women than to men, as the fact of having the body covered with dust when unloading charcoal, manual labor and contact with high temperatures.

Likewise, in the steel industry women account for only 7% of the labor force. The justification is also related to the fact that most industrial functions demand physical effort and are hazardous, which are situations more sensitive to women.

Most kiln operators earn the minimum wage plus production. Carbonizers earn, on average, one and a half minimum wage plus production. Data were gathered through a survey with the sector.

3.4 - Economic analysis

In economic terms, the Discounted Cash Flow (DCF) method was employed to assess the charcoal production technologies.

The DCF is the difference between the volume of inflowing resources and the out flowing volume. In other works, it is the operational profit after taxes, plus non-cash charge, less investments in operational working capital, facilities, equipment and other assets (FELIPETTO, 2007).

The table used to evaluate the economic feasibility of the carbonization technologies is shown below.

Table 3 - DCF methodology schedule

PROJECTED CASH FLOW
Total Annual Charcoal Production of the Carbonization Technology
Charcoal Price (R$/t.cv)
Gross Revenue (R$/year)
(-) Taxes on Revenue (R$/year)

Net Revenue (R$/year)
(-) Carbonized Raw Material Cost
Operational Costs (R$/year)
(-) Technology Operation and Maintenance
(-) Administrative Costs (Overhead)
(-) Other Costs
Total Operational Costs (OPEX) - (R$/year)
Gross Margin (R$/year)
(-) Investment in Project Implementation - (CAPEX)
Free Cash Flow - FCF (r$/YEAR)

3.3.1. Economic Indicators:

- Minimum attractiveness rate (MAR) higher than the IRR.
- Current net value (CNV): tending to 0 to reach the MAR.
- Internal return rate (IRR): 7.5% a year.
- Payback time: the shorter, the better.

Minimum attractiveness rate (MAR)

It establishes the reference basis to evaluate the project attractiveness.

- Base value: The MAR adopted for the economic analysis of the technologies was 7.5%. The amount corresponds to the maximum interest rate charged by the *Fundo Clima* Program, in the Charcoal sub-program.

Current net value (CNV)

It is equal to the current value of the net cash flow [- NCF] of the project under analysis, discounted by the weighted average capital cost (Portal de Contabilidade, 2017).

Internal return rate (IRR)

It is the ‘i’ rate that equates the periodic cash inflow and outflow to the amount to be invested in a project. In other words, it is the rate that equates the CNV of a project to zero (Portal de Contabilidade, 2017).

The **IRR** found was compared to the **MAR** to support the investment feasibility, as follows:

- **IRR higher than the Minimum Attractiveness Rate:** It means that investment is economically attractive.
- **IRR equal to the Minimum Attractiveness Rate:** In economic terms, the investment is in a situation of indifference.
- **IRR lower than the Minimum Attractiveness Rate:** The investment is not economically attractive, since its return is lower than the return of a risk-free investment.

Payback time

Time span required for the project cash inflow to equalize with the amount to be invested, i.e., the time to recover the investment made (Portal de Contabilidade, 2017).

- In this analysis, the shorter payback, lower is the economic risk of the technology.

Table 4 - Summary Chart of the Methodology to Evaluate the Charcoal Production Chains

Análse Técnica

- Obtenção do Rendimento do Processo via metodologia ACM0021
- Valores maiores que 25% e que atendam a qualidade química do carvão vegetal: Carbono Fixo entre 70 a 80%

- Obtenção da Qualidade do Carvão Vegetal
- Carbono fixo: de 70 a 80%
- Densidade a granel: maior que 180 kg/m3
- Umidade: menor que 8%
- Finos de Carvão Vegeal: menor que 25%

Análise Ambiental

- Capacidade de redução de gás metano (CH4)
- Associado ao valor do rendimento gravimétrico (RG): quanto maior o RG, maior a redução de emissão do gás metano

- Capacidade de recuperação de coprodutos
- Valores obtidos dependentes da tecnologia utilizada para recuperação das fumaças

Análise Econômica

- Metodologia: Método do Fluxo de Caixa Descontado - FCD
- Produção Anual de Carvão Vegetal
- Preço do Carvão Vegetal
- Impostos
- Custo da Matéria Prima
- Custos Operacionais - OPEX
- Investimento na implantação do projeto - CAPEX

- Indicadores Econômicos
- Taxa Mínima de Atratividade - TMA = 7,5%
- Valor Presente Líquido - VPL
- Taxa Interna de Retorno - TIR
- Comparação entre TIR e TMA. Projeto Viável Economicamente para TIR > TMA
- Tempo de Retorno de Investimento - Payback: quanto menor, melhor e menos risco do empreendimento

Análise Social

- Identificação de Mudanças, positivas ou negativas, que afetem indivíduos ou comunidade devido à implantação das tecnologias de produção de carvão vegetal

- Avaliação Inicial de Impactos Sociais - AIIS
- Visitas, entrevistas à comunidade e atores onde a tecnologia estiver inserida
- Qual será o impacto do projeto sobre a inclusão social e a geração de renda das pessoas envolvidas?
- Quais as possibilidades oferecidas pela tecnologia quanto à redução da desigualdade de gênero?

4. Diagnosis of the state-of-the-art of production chains and carbonization technologies

The diagnosis of the state-of-the-art of production chains and carbonization technologies summarized herein was prepared based on the findings of the following stages of the study 'Charcoal Production Chains for the Steel Sector':

- Analysis of the state-of-the-art of charcoal production chains for the pig iron, ferroalloy and steel sector.
- Comparative analysis of the state-of-the-art technologies for the production of charcoal for the pig iron, ferroalloy and steel sector.

Both analyses were developed considering the methodology proposed in the first stage of the study 'Charcoal Production Chains for the Steel Sector'.

4.1 - Technical analysis

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The technical description of masonry brick kilns pointed out gravimetric yield of 26%, which is the major point of attention highlighted by the author, since in the light of economic feasibility the minimum recommended index is 33%. The fact that the masonry brick kilns temperature is empirically controlled by carbonizers is a critical factor for the low performance.

Therefore, the use of peripherals to control the masonry brick kilns temperature is a turning point to raise the gravimetric yield - the most relevant index of the carbonization process.

There are also cultural barriers that hinder adopting the peripherals. These are related to the carbonizers' and entrepreneurs' resistance against adopting this sort of system, as they do not accept or believe in the scientific consensus about how the charcoal production yield could be increased.

The technical description of metallic and hybrid kilns points out gravimetric yield ranging from 33% to 38% because these technologies are equipped with peripheral systems to control the carbonization process temperature.

4.2 - Environmental analysis

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According to the environmental description of the masonry brick kilns, both circular and rectangular ones, these report high methane gas emissions percentages because of their low gravimetric yield.

On the other hand, according to the environmental description of metallic and hybrid kilns, these present low percentage of methane gas emissions because of their high gravimetric yield.

Therefore, the increase of gravimetric yield and the capacity of reducing methane gas emission is a challenge that metallic and hybrid technologies have overcome, according to the proposed methodology presented by the author.

The restrictions and barriers posed to the adoption of metallic technologies are mainly related to technical factors, since there is no large-scale operation unit that could validate the results presented.

For hybrid technology, the critical point to be surmounted is that it is an innovation, and the steel industry is resistant to investments in new charcoal production technologies.

4.3 - Social analysis

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In the social light, it is worth mentioning that, on one hand, circular masonry brick kilns offer more job opportunities in the charcoal production chains, considering the social inclusion of male rural workers, illiterate workers who work as kiln operator and carbonizer.

However, on the other hand the circular masonry brick kiln also report social exclusion of women. This could be changed if production chains adopt rectangular kilns with temperature control of the carbonization process, or metallic and hybrid technologies.

As the adoption of new carbonization technologies, in the author’s view, tends to become reality for environmental and economic reasons, the workers today working as kiln operator and carbonizer at circular and rectangular masonry brick kiln could be inserted in literacy-building and fundamental education programs to be skilled to the new functions.

4.4 - Economic analysis

The economic feasibility study of the charcoal production is very complex, since it involves a huge number of variables from raw material to the charcoal market sales price. Therefore, the author established several assumptions to the economic analysis.

Table 5 = Assumptions adopted for the economic feasibility analysis of the charcoal production technologies in Minas Gerais.

PREMISSA	DESCRIÇÃO		unid	Mínimo	Médio	Máximo	Referencial da faixa de valores adotada	Fonte
1ª	A	FE = Fator de empilhamento da madeira nos fornos (% de volume nominal)	%		68,50%		Valor para quantificar a madeira enfornada em volume sólido a partir do volume do forno	Consultoria
2ª	B	Capacidade de processamento de madeira	m^3/mês		3000		Ponto de partida para dimensionamento da quantidade de fornos da tecnologia avaliada	Consultoria
3ª	C	Densidade básica da madeira	kg/m^3	450	500	550	Qualidade da floresta plantada (Tipo de Clone)	MDIC
4ª	D	Rendimento Gravimétrico do Processo	%	28%	33%	38%	Dependente da tecnologia de produção de carvão vegetal adotada	MDIC
5ª	E	Preço da Madeira em pé	R$/$m^3$	32,00	36,00	40,00	Médias de mercado em diferentes regiões de Minas Gerais	Mercado
	F	Preço da colheita florestal	R$/$m^3$	12,00	15,00	18,00	Manual, semi-mecanizada e mecanizada	Mercado
	G	Preço do transporte de madeira	R$/$m^3$	6,00	9,00	12,00	Médias de mercado variando em função das distâncias de transporte	Mercado
6ª	H	Preço do carvão vegetal na UPC	R$/t	450,00	500,00	550,00	Valor variável do mercado em diferentes períodos dos últimos anos	Mercado
	I	Preço do frete do carvão vegetal	R$/t		100		Distância média de 300 km de raio das UPCs até as usinas siderúrgicas de Minas Gerais	Mercado
CÁLCULOS DAS CAPACIDADES PRODUTIVAS DE CARVÃO VEGETAL	J	Produção de carvão vegetal em massa	t/mês	378	495	627	I = (B x C x D) / 1000	Equação
	K	Densidade a granel do carvão vegetal	kg/mdc		200		Média de mercado	Consultoria
	L	Produção de carvão vegetal em volume	mdc/mês	1890	2475	3135	L = J / (K/1000)	Equação

Remark: Average value = (minimum value + maximum value)/2

Considering the assumptions adopted to make up the Discounted Cash Flow (DCF) of each technology, the following summarized outcomes were achieved:

Table 6 - Result of the economic analyses of the technologies considered

ITEM	Tecnologia Avaliada	RG	Preço de Venda do CV	Tempo de Retorno (Payback)	Resultado VPL	Sucesso na Viabilidade Econômica	Análise dos resultados de viabilidade econômica
		%	R$/t.cv	(anos)	KR$	Probabilidade	
3.2.4.1	Forno tipo circular com carga e descarga feitos de forma manual	26%	550	10,0	-6562	Inviável	Fornos controlados apenas pelo fluxo das fumaças sempre irão tender para rendimentos baixos (<28%), pois o processo só se encerra quando as reações químicas de decomposição térmica da madeira forem desprezíveis. Dessa forma e nas premissas atuais esses modelos **não se viabilizam** se não forem dotados de controles de processo de carbonização (temperatura e fluxos de entrada de ar)
			600	10,0	-4985	Inviável	
			650	10,0	-3379	Inviável	
3.2.4.2	Forno Tipo Circular – Semi-Mecanizado (carga manual e descarga mecanizada)	26%	550	10,0	-5786	Inviável	
			600	10,0	-4180	Inviável	
			650	10,0	-2573	Inviável	
3.2.4.3	Forno Retangular Pequeno com carga e descarga mecanizada	33%	550	10,0	-3313	Inviável	Mesmo com controle de processo, que permite chegar a RG=33%, só se torna viável para preços do CV acima de R$650/t e mesmo assim com alto tempo de retorno. As Tecnologias apresentaram um **alto risco** nas premissas econômicas adotadas no presente estudo.
			600	10,0	-1274	Inviável	
			650	7,2	765	Baixa	
3.2.4.4	Forno Retangular Médio com carga e descarga mecanizada	33%	550	10,0	-2915	Inviável	
			600	10,0	-876	Inviável	
			650	6,3	1163	Média	
3.2.4.5	Forno Retangular Grande com carga e descarga mecanizada	33%	550	10,0	-2572	Inviável	Tecnologia apresentou uma TIR de 21% (quase 3 vezes a TMA de 7,5%), o que é bem positivo. O risco continua sendo a dependência do preço mínimo do carvão em torno de R$650/t.
			600	10,0	-190	Inviável	
			650	5,0	1848	Alta	
3.2.4.6	Forno DCP com carga e descarga mecanizada	38%	550	9,0	299	Baixa	Com TIR atingindo de 20 a 30% e para os cenários de payback menores que 6 anos, a tencologia se torna bem atrativa do ponto do vista econômico. O risco nesse caso é a sua validação técnica da performance em escala industrial
			600	5,3	2647	Média	
			650	3,6	4994	Alta	
3.2.4.7	Forno ONDATEC com carga e descarga mecanizada	38%	550	10,0	-1149	Inviável	Com TIR atingindo 22% e para o cenário de payback menores que 5 anos, a tencologia se torna bem atrativa do ponto do vista econômico. O risco nesse caso é a sua validação técnica da performance e a dependência do preço acima de R$650/t.
			600	7,3	1199	Baixa	
			650	4,8	3547	Alta	
3.2.4.8	Forno SISTEMA VEREDAS com carga e descarga mecanizada	33%	550	10,0	-1087	Inviável	Com TIR atingindo de 18 a 36% e para os cenários de payback menores que 6 anos, a tencologia se torna bem atrativa do ponto do vista econômico. O risco nesse caso é a sua validação técnica da performance em escala industrial
			600	5,8	952	Média	
			650	3,3	2991	Alta	

4.4.1 - Sensitiveness analysis

In order to compare the economic analyses findings for the different charcoal production technologies, the following sensitiveness study was prepared. In it, the wood density, gravimetric yield and charcoal price vary.

It simulates the wood remuneration value in the charcoal production unit (R$/m^3), through mathematical iteration, to each scenario in order to reach CNV = 0 to IRR = MAR = 7.4%. The scenarios combined the following parameters:

- Charcoal price: R$ 550 /t.cv, R$ 600 /t.cv and R$ 650 /t.cv;
- Wood density: 450 kg/m^3, 500 kg/m^3 and 550 kg/m^3;
- Gravimetric yield: GY = 28%, 33% and 38%;

The consultancy classified the scenarios outcomes as follows:

Table 7 - Enterprise risk range

Range of wood prices obtained in the Scenarios simulation			
< R$ 50.00	R$ 50,00 <= AP < R$ 60	R$ 60.00 <= AP < R$ 70	>= R$ 70.00
Unfeasible	**High Risk**	**Medium Risk**	**Low Risk**

Table 8 - Scenarios to simulate economic sensitivity analyses to each technology, with charcoal price varying on R$550/t.cv, R$600/t.cv, R$650/t.cv.

Wood density Kg/m^3	GY - Gravimetric Yield		
	28%	33%	38%
450	Scenario A1	Scenario A2	Scenario A3
500	Scenario B1	Scenario B2	Scenario B3
550	Scenario C1	Scenario C2	Scenario C3

In the quantitative light, the findings of the economic analyses of different charcoal production technologies were fit into the following mathematical formulation proposed by the author:

- **Objective**: obtain **a** likely average price of wood remuneration among the values simulated in the economic sensitiveness analysis, where the following varied: wood density, process performance and charcoal price.

- **Score of the combination of simulated outcomes to each technology**

$$PTS_{TEC} = \sum_{S=1}^{S=27} (PMI_S \times PROB_{RG}) \quad (7)$$

Where:

- **PTS_{TEC}** = Score of the combination of simulated outcomes of each technology;
- **PMI_S** = Wood price for each individual simulation (R$/m^3);
- **S** = Corresponding simulation index;
- **$PROB_{RG}$**= Qualitative likelihood of achieving gravimetric yield GY:

Table 9 - Range of likelihood of achieving efficiency from the evaluated technologies

Probabilidade de obtenção do RG pela tecnologia avaliada			
ALTA	MÉDIA	BAIXA	DESPREZÍVEL
3	**2**	**1**	**0**

- **Obtaining the percentage of PTS obtained by each technology**

$$\%PER_{TEC} = \left(\frac{PTS}{PTS_{MAX}}\right) \times 100\% \quad (8)$$

Where:

- **$\%PER_{TEC}$** = Percentage obtained from each technology in relation to the maximum score;
- **PTS_{MAX}** = Maximum score = sum of scores obtained by each technology (PTS);

- **Obtaining the likely average wood remuneration value**

$$VPM_{TEC} = PER_{TEC} \times VPM_{MAX} \quad (9)$$

Where:

- **VPM_{TEC}** = Likely average wood remuneration price (R$/m^3);
- **VPM_{TEC}** = Likely maximum wood remuneration price among the technologies assessed (R$/m^3);

It is worth mentioning that the analyses details such as operational costs, teams and equipment sizing, investments, among others, can be consulted at:

https://drive.google.com/open?id=1NVVVxZ7L3QIXVhH2FEZjmLJqE3Hfq2xk

Table 10 - Result of the combined economic analyses of the technologies considered

TECNOLOGIA	PROBABILIDADE DE OCORRÊNCIA DO RENDIMENTO GRAVIMÉTRICO			PREÇO DO CARVÃO VEGETAL	R$ 550 /t.cv			R$ 600 /t.cv			R$ 650 /t.cv			PONTUAÇÃO		Valor Provável Madeira
				DENSIDADE DA MADEIRA	RENDIMENTO GRAVIMÉTRICO			RENDIMENTO GRAVIMÉTRICO			RENDIMENTO GRAVIMÉTRICO			PTS	%PER	VMP
	28%	33%	38%	(kg/m³)	28%	33%	38%	28%	33%	38%	28%	33%	38%	3154	100%	83
Tipo Rabo Quente	3	1	0	450	32	45	57	38	51	65	44	59	73	1804	57%	48
				500	40	54	67	46	61	76	53	69	85			
				550	48	63	78	55	71	88	62	80	98			
Circulares de 5M	3	1	0	450	35	47	59	41	54	68	47	62	77	1910	61%	50
				500	42	56	70	49	64	79	56	72	88			
				550	50	65	80	58	74	91	65	83	101			
Retangulares Grandes	2	3	0	450	30	42	55	36	50	63	42	57	72	2405	76%	64
				500	37	51	65	44	59	74	51	67	84			
				550	45	60	75	53	69	86	61	79	96			
Retangulares Médios	2	3	0	450	27	39	52	33	47	60	40	54	69	2280	72%	60
				500	35	48	62	42	56	71	49	65	81			
				550	42	58	73	50	67	83	58	76	94			
Retangulares Pequenos	2	3	0	450	25	38	50	32	45	59	38	53	67	2208	70%	58
				500	33	47	60	40	55	70	47	63	79			
				550	41	56	71	49	65	82	56	74	92			
Fornos DPC	1	3	2	450	26	39	51	33	46	60	39	54	68	3154	100%	83
				500	34	48	61	41	56	71	48	64	80			
				550	42	57	72	49	66	82	57	75	93			
Fornos ONDATEC	1	3	2	450	20	33	45	27	40	54	33	48	62	2839	90%	75
				500	28	42	55	35	50	65	42	58	74			
				550	36	51	66	44	60	77	51	69	87			
Fornos VEREDAS	2	3	0	450	34	47	59	41	54	68	47	62	76	2613	83%	69
				500	42	56	69	49	64	79	56	72	88			
				550	50	65	80	58	74	91	65	83	101			

Source: Own elaboration

- The DPC and ONDATEC technologies were outstanding with **low economic risk** results, mainly due to the high likelihood of achieving gravimetric yields (GY) ranging between 33% and 38%;

- The **medium economic risk** range comprised the technologies of Rectangular brick kilns (big and medium size) because of the scale gain in relation to circular and *rabo-quente* brick kilns, and the VEREDAS oven due to its low investments required in comparison with the Rectangular brick kilns;

- Small rectangular brick kilns and Circular 5M brick kilns were in the **high economic risk** range, while the *rabo-quente* brick kilns proved to be **unfeasible**, mainly due to the high likelihood of low GY.

4.4.2. Complementary analyses

In the qualitative light, the charcoal production technologies were also analyzed observing the following topics:

Operational conditions of kilns and occupational safety:

- Kilns operation - carbonization process control
- Explosion hazard
- Workers' contact with toxic gases - carbon monoxide (CO)

Charcoal product quality:

- Fixed carbon content; Charcoal moisture; Generation of fines and ashes

System of burn of carbonization smokes or smokes reclaim:

- Synchronism of kilns x stable smokes burn
- Smokes condensation ducts
- Collector/burner/chimney set

A scoring system was set to each topic, as follows:

Table 11 - Qualitative analysis of the technologies assessed

CRITÉRIO DE AVALIAÇÃO DA ANÁLISE QUALITATIVA - AQ				
Qualificação	Ótimo	Bom	Regular	Ponto de Atenção
Pontuação Individual	3	2	1	0
Resultado %	AQ > 90 %	70 % <= AQ < 90 %	50 % <= AQ < 70 %	<= 50 %

QUADRO RESUMO - ANÁLISE QUALITATIVA						
Item de Avaliação	Fornos de Alvenaria			Fornos Metálicos e Híbridos		
	Tipo Rabo Quente e Circulares	Retangulares Médio e Grande Porte	Retangulares de Pequeno Porte	DPC	ONDATEC	VEREDAS
Condições Operacionais e Segurança do Trabalho	7	10	10	13	13	13
Qualidade do Carvão Vegetal	8	5	6	12	12	10
Sistema de queima das fumaças ou condensação de pirolenhoso e alcatrão	1	3	3	9	9	8
Resultado qualitativo	**16**	**18**	**19**	**34**	**34**	**31**
Condições Operacionais e Segurança do Trabalho	47%	67%	67%	87%	87%	87%
Qualidade do Carvão Vegetal	67%	42%	50%	100%	100%	83%
Sistema de queima das fumaças ou condensação de pirolenhoso e alcatrão	11%	33%	33%	100%	100%	89%
% em relação ao Máximo de 36 pts	44%	50%	53%	94%	94%	86%

Maximum score: 36. - Source: Own elaboration

The qualitative analyses that gave rise to the scores shown in table XXX are detailed at:

https://drive.google.com/open?id=1NVVVxZ7L3QIXVhH2FEZjmLJqE3Hfq2xk

5. Proposals to improve the performance of the renewable charcoal production for the pig iron, steel and ferroalloys sector in Brazil, mainly focusing on the state of Minas Gerais

For circular masonry brick kilns for large-scale production (above 1000 mdc/month), the consultancy considers that no improvement proposal is promising, and recommends replacing those kilns for others that allow mechanizing the wood loading and charcoal unloading. For small-scale productions (on average below 500 mdc/month), if mechanization is unfeasible, it is recommended to at least implement temperature controls.

The reason for recommending the replacement of circular masonry kilns is the intensive labor force use that is resistant to the implementation of systems to control the process temperature. Moreover, it builds negative image to the charcoal production chain historically associated to the use of practices akin to slavery.

The rectangular masonry kilns are alternates to the circular masonry brick kilns, provided the first are improved mainly regarding the entrepreneurs' adherence to the carbonization process control systems.

Still in this sense, the consultancy suggested that carbonization plants should be managed by engineers, and entrepreneurs should be more interested in diversifying the charcoal production chain to become independent from the steel industry market, conversing smokes into products such as the bio-oil produced through the vegetal tar reclaim.

The charcoal production chain diversification is the way to be followed to value the business and raise entrepreneurs' interest in investing in technology, machinery and skilled labor force. This is not a reality today, as most of the chains produce one single product with value pushed by the high price paid for the wood and low price paid for pig iron.

As regards environmental issues, the improvements proposed to increase the capacity of reducing methane gas emissions in rectangular masonry brick kilns, these involve the use of systems to control the process temperature. As noticed, this adoption will mainly depend on the entrepreneurs' adherence.

As regards the increased capacity of reclaiming condensable gases, the consultancy proposed improvements that would allow installing condensation systems. Improvements refer to replacing the parallel layout found in most of the carbonization plants by others that allow channeling gases and the central positioning of the condenser.

Also crucial is to have energy to operate the condensation system. Here, the consultancy recommends installing photovoltaic solar panels in sites not served by electric power grids.

As regards metallic and hybrid technologies, no proposal was presented for the gravimetric yield as kilns come standard with system to control the carbonization process temperature and, therefore, reach higher gravimetric yield.

And for reaching higher gravimetric yield, the metallic and hybrid kilns report higher capacity of reducing methane gas, which waived any recommended improvement for this purpose.

In terms of capacity to reclaim condensable gases, the consultancy restates the need for energy and presents recommendations for improvement involving the development of product and market related to the carbonization co-products, notably the bio-oil which is the potential substitute of the fossil-based oils.

In the social scope, improvements were recommended involving increased social inclusion of women and, therefore, reduction of gender inequality in the charcoal production chain.

Above all, the social improvements involve the adoption of kilns that allow mechanizing the loading and unloading and the use of systems to control the carbonization process, since in these instances women could be included in job opportunities.

In economic terms, the consultancy recommends technical improvements to increase gravimetric yield and the reclaim of smokes to produce co-products, as shown in table 12.

Table 12 - Comparative financial results between the state-of-the-art technologies and the implementation of improvements in the charcoal production chains

Tecnologia Avaliada	RG	Preço de Venda do Carvão Vegetal	ESTADO DA ARTE			MELHORIAS TECNOLÓGICAS			Tipo de Melhoria Adotada	Análise dos resultados de viabilidade econômica
			Tempo de Retorno (Payback)	Resultado VPL	Sucesso na Viabilidade Econômica	Tempo de Retorno (Payback)	Resultado VPL	Sucesso na Viabilidade Econômica		
	%	R$/t.cv	(anos)	KR$	PROBABILIDADE	(anos)	KR$	PROBABILIDADE		
Forno tipo circular com carga e descarga feitos de forma manual	28% p/ 33%	550	10	-6562	Inviável	10,0	-1599	Inviável	Controle de Processo RG de 28% para 33%	A implantação de sistemas de controle de processo (temperatura) melhorou significativamente os resultados desse tipo de tecnologia, que antes eram totalmente inviáveis.
		600	10	-4985	Inviável	6,7	440	Baixa		
		650	10	-3379	Inviável	1,7	2478	Alta		
Forno Tipo Circular – Semi-Mecanizado (carga manual e descarga mecanizada)	28% p/ 33%	550	10	-5786	Inviável	10,0	-1029	Inviável		
		600	10	-4180	Inviável	4,8	1009	Média		
		650	10	-2573	Inviável	1,8	3048	Alta		
Forno Retangular Pequeno com carga e descarga mecanizada	33%	550	10	-3313	Inviável	10,0	-1364	Inviável	Implantação de cadeia de produção de Bioóleo	A implantação de cadeia de produção de bioóleo melhorou significativamente os resultados desse tipo de tecnologia, reduzindo muito a dependência do preço do carvão vegetal
		600	10	-1274	Inviável	7,7	674	Baixa		
		650	7,24	765	Baixa	4,6	2713	Alta		
Forno Retangular Médio com carga e descarga mecanizada	33%	550	10	-2915	Inviável	10,0	-966	Inviável		
		600	10	-876	Inviável	6,8	1073	Baixa		
		650	6,3	1163	Média	4,2	3111	Alta		
Forno Retangular Grande com carga e descarga mecanizada	33%	550	10	-2572	Inviável	10,0	-281	Inviável		
		600	10	-190	Inviável	5,5	1758	Média		
		650	5	1848	Alta	3,6	3797	Alta		
Forno DCP com carga e descarga mecanizada	38%	550	9	299	Baixa	9,0	299	Baixa	Sem alteração do projeto original	Não foi sugerido mudanças do projeto original por serem tecnologias que já atingem altas performances de RG
		600	5,3	2647	Média	5,3	2647	Média		
		650	3,6	4994	Alta	3,6	4994	Alta		
Forno ONDATEC com carga e descarga mecanizada	38%	550	10	-1149	Inviável	10,0	-1149	Inviável		
		600	7,3	1199	Baixa	7,3	1199	Baixa		
		650	4,8	3547	Alta	4,8	3547	Alta		
Forno SISTEMA VEREDAS com carga e descarga mecanizada	33%	550	10	-1087	Inviável	6,5	862	Baixa	Cadeia de Produção de Bioóleo	A implantação de cadeia de produção de bioóleo melhorou significativamente os resultados desse tipo de tecnologia praticamente a viabilizando para todas as faixas de preço de carvão vegetal simuladas
		600	5,8	952	Média	3,6	2900	Alta		
		650	3,3	2991	Alta	2,5	4939	Alta		

6. Conclusion

The studies performed showed the vital importance of valuing the different factors that impact the sustainability results of the charcoal production sector in Brazil. The most impacting parameters are: mechanization of wood loading and charcoal unloading; process yield; and, use of co-products.

Therefore, in this consultancy's view the first step towards a strategy to promote the use of charcoal in the steel industry is to mechanize the production, since the intensive use of labor force contributes to maintain the carbonization sector in a pre-industrial stage with the inherent consequences, mainly those regarding the negative image in social terms.

The rectangular masonry brick kilns and the metallic and hybrid kilns are totally mechanized and should be supported as an alternate to the circular masonry brick kilns for large-scale production (above 1000 mdc/month).

After promoting mechanization at the largest scale possible, the strategy to promote the use of charcoal in the steel industry should focus on increasing the gravimetric yield. This could be achieved using peripheral systems to control the carbonization process temperature.

Provided that equipped with peripheral systems to control the carbonization process temperature, the rectangular masonry brick kilns, jointly with metallic and hybrid kilns, should be supported as alternate to kilns monitored by the carbonizer.

A third recommendation to the strategy to promote the use of charcoal in the steel industry should focus on projects that research and develop the reclaim of condensable gases, and potential production of carbonization co-products. This would allow the chain diversification, thus reducing its dependence on the wood and pig iron market variations.

The consultancy reaffirms the need for producing and sharing updated information on the existing scientific consensus about the use of charcoal in the steel industry, to assist the entrepreneurs to modernize the production chain, and raise the society's awareness about the relevance of using charcoal.

Finally, it should be said that the Sustainable Steel Industry Project is an ongoing action that is responding to or intends to respond to the improvements proposed by the consultancy. Therefore, it contributes to reduce the restrictions and barriers that hinder improving the environmental, social and economic sustainability of the charcoal production chains performance in Brazil, notably in Minas Gerais.

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