Analysis of the concentration of charcoal production in Pará, Brazil: an auxiliary tool for sustainable development and public policies

Alisson Rodrigo Souza Reis [1*] *Matheus da Costa Gondim* [2]

[1] Universidade Federal do Pará, Rua Coronel José Porfírio, São Sebastiao, CEP 68372-191, Altamira, PA Brasil
[2] Universidade Federal Rural da Amazônia, Estrada Principal da UFRA, 2150 - Curió Utinga, Belém, PA, Brasil

ABSTRACT: Over time, charcoal has been an important input for power generation, being used for basic purposes such as cooking food and also contributing to technological development. This study evaluated the regional concentration of charcoal production in the state of Pará, Brazil. Data used in this analysis were obtained from the Data Recovery System (SIDRA) of the Brazilian Institute of Geography and Statistics (IBGE) from 1990 to 2017. The indicators used were: Concentration Ratio (CR(k)), Herfindahl-Hirschman Index (HHI), Theil Entropy Index (EI), and Gini Index (G). Main results indicate that most charcoal production is from Southeast and Northeast Pará mesoregions. The CR(k) showed an extremely high concentration for both municipalities and microregions, HHI and EI tended toward high concentration and monopolized markets, G showed that inequality ranges from very strong to absolute in the municipalities and, for most of the period, in mesoregions and microregions, except for 2004. Therefore, we inferred that the concentration of charcoal production at regional levels is concentrated throughout the state.

Análise da concentração da produção de carvão vegetal no Pará, Brasil: ferramenta auxiliar de gestão, fiscalização, desenvolvimento sustentável e políticas públicas.

RESUMO: Ao longo do tempo o carvão vegetal tem sido um importante insumo para geração de energia, sendo utilizado para fins básicos como cocção de alimentos e contribuindo até para o desenvolvimento tecnológico siderúrgico do estado do Pará. Deste modo, este trabalho teve como objetivo analisar a concentração regional da produção de carvão vegetal no estado do Pará. Os dados para a análise foram obtidos no Sistema de Recuperação de Dados (SIDRA) do Instituto Brasileiro de Geografia e Estatística (IBGE), no período de 1990 a 2017. Os indicadores utilizados foram a Razão de Concentração [CR(k)], o Índice de Herfindahl-Hirschman (IHH), o índice de entropia de Theil (E) e o Índice de Gini (G). Os principais resultados mostram que as mesorregiões da Sudeste e Nordeste do Pará concentram a maior parte da produção de carvão vegetal. O CR(k) tanto para os municípios quanto para as microrregiões apresentaram concentração extrema; o IHH e E mostraram tendências de concentração apresentando mercados monopolizados; o G mostrou que a desigualdade tende de muito forte a absoluta para os municípios e na maioria do período para as mesorregiões e microrregiões, salvo o ano de 2004. Nesse sentido, infere-se que a concentração da produção do carvão vegetal nos níveis regionais é concentrada em Munícipios do sudeste paraense.

Introduction

Over time, charcoal has been an important input for power generation, being used for basic purposes such as cooking food and also contributing to technological development. This product became important during World War II, when scientific attention turned to the different ways of obtaining this source of energy (Peláez-Samaniego et al., 2008; Passos et al., 2015). Charcoal became one of the most important renewable energy sources worldwide, due to its significance and versatile use (Rodrigues & Braghini Junior, 2019).

Global charcoal production has tripled in the last 50 years, increasing from 17.3 million tons in 1964 tcrio 53.1 million tons in 2014 (Rodrigues & Braghini Junior, 2019).

According to IBA (2020), Brazil is the main producer of charcoal in the world, corresponding to about 12% of world production. In 2019, this sector grew by 3.7%, reaching 5.3 million tons. Internally, the state of Minas Gerais is the largest consumer and the state of Pará has 2 production units that correspond to approximately 1.1% of national production.

However, this quantity considers only forests planted for this purpose, disregarding artisanal production and those originating from forestry residues that do not have official data on production, market, and concentration. Charcoal is also important in the industrial sector, especially in pig iron and steel production, occupying a prominent position in Brazilian production.

Given the importance of pig iron production in the regional, national and international economy, the Carajás forest fund was created in the last century, whose objective was to create financial conditions for the planting of energy forests, optimizing the production of charcoal in the State of Pará, in addition to reducing pressure on native wood charcoal.

Although less significant, charcoal from native forests is also included in this framework as it supplies energy plantations, industrial sector, thermoelectric plants, chemical industry, and other consumer cores, such as residences, with charcoal for power supply, generated from residues of the lumber industry (Numazawa, 1986; Rodrigues & Braghini Junior, 2019).

The disordered exploitation of forest resources in the Amazon has led to several recurrent environmental problems, namely, loss of biodiversity, reduced supply of raw materials for energy production, increase in the number of unproductive areas, reduction of rainfall regimes, etc. It is one of the destinations for the wood of this disordered exploration and the production of charcoal, which occasionally enters this market, without taking into account the legal, social and environmental aspects.

This scenario is a consequence of depleted energy resources in the South and Southeast of the country, in addition to the opening of new roads encouraged by government development projects in the 1960s, when intense migration occurred and the state of Pará was the gateway to predatory logging activity in the Amazon. Therefore, forces were joined due to these concerns, reflecting several enforcement actions by environmental agencies, forcing energy production from planted forests, especially in the South and Southeast regions (Monteiro, 2006; Amaral, 2011).

Although the region has a lot of sustainable and legalized forestry activity, there are those who do not. Logging is considered a non-sustainable activity and takes place mainly in the region known as the Arc of Deforestation, which encompasses the states of Mato Grosso, Rondônia, and Tocantins, as well as parts of Southeast and Northeast Pará, Southeast Acre, and South Amapá, and is concentrated on logging activity and, consequently, on charcoal production (Diniz et al., 2009). According to IBGE surveys (2019), an area of approximately 5,000 km² of the Legal Amazon was destined for charcoal production, highlighting the state of Pará, where 1,829 km² were destined for this purpose in 2014. The North of Brazil still suffers from illegal logging and production of wood and charcoal. Even with a high productivity of Brazilian forestry, planted forests are still unable to support demand from all industries, with a 50% shortage occurring every year, which is supplied by natural forests (Calais, 2009).

In view of the economic fluctuation and environmental degradation issues reported in the Amazon, it is important to verify indicators that provide data on the participation and dynamics of forest-based products, both in the domestic and foreign markets. These indicators reflect the degree of concentration and competitiveness of the products, as mentioned by Resende (1994); Matsumoto et al. (2012); Busu (2012) and Rhoades (1993) thus reflecting on the formulation of public policies and a better understanding of this market, helping mainly in the economy, but also in the social and environmental issues of the Amazon region.

About forest-based products, several studies were carried out and exposed the behavior of the market for various products, among which the works of Coelho Junior et al (2010, 2018a) and Costa et al (2018) stand out. pulp market under several aspects. Coelho junior (2016) verified the regional concentration of pinhão in the State of Paraná. Filgueiras et al (2017) observed the log wood market in the State of Pará and Coelho junior et al (2018b, 2019a, 2019b) reported on the concentration of the firewood market in the State of Paraíba

In view of this environmental problem, this study sought to identify the concentration of

production in the state of Pará between 1990 and 2017, highlighting the need to understand the distribution of the market for the promotion of public policies, inspection and environmental conservation.

Material and Methods
Data acquisition

The state of Pará spans over a territory of 1,245,759.305 km², distributed among 6 mesoregions, 22 microregions, and 144 municipalities (figure 1) (IBGE, 2019). Charcoal production fell around 32.5% between 1990 and 2017, from 71,599 thousand tons to 23,317 thousand tons. This reduction is primarily explained by the reduced.
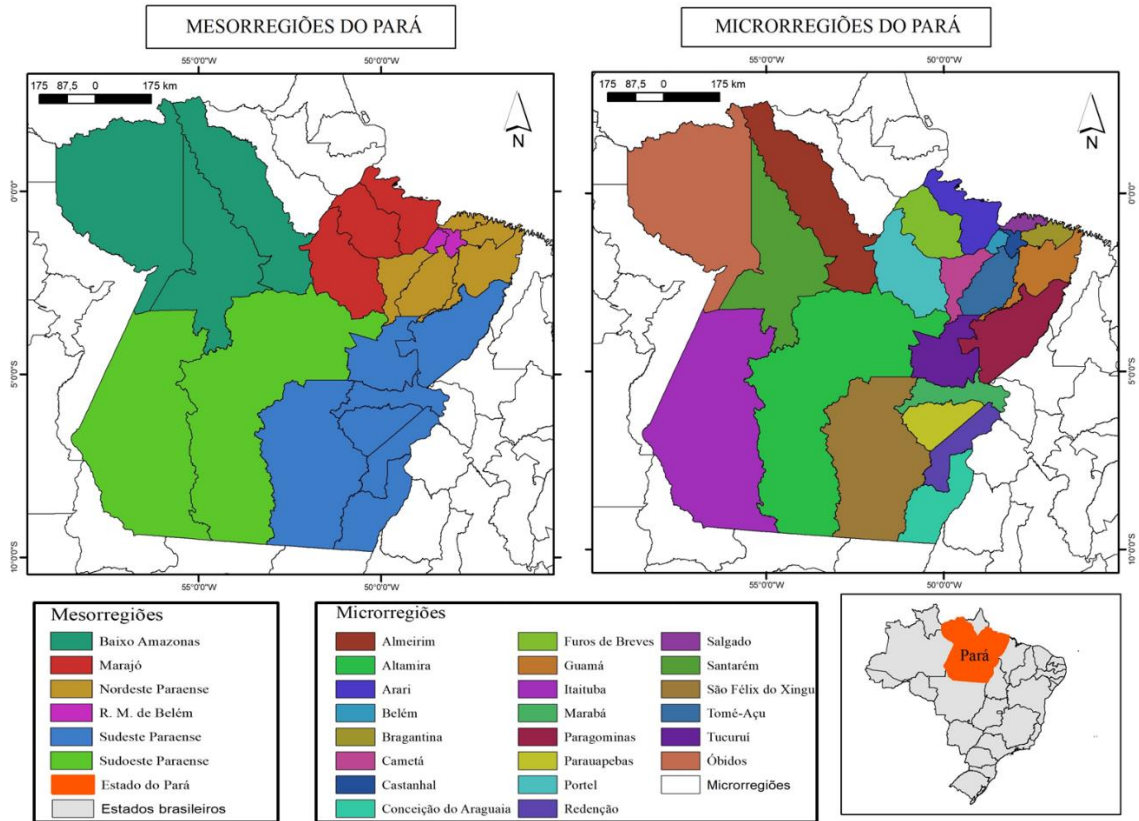

Figure 1: Geopolitical division in mesoregions and microregions of Pará

Data used to determine the regional concentration of native charcoal produced in Pará were obtained from the Data Recovery System (SIDRA) of the Brazilian Institute of Geography and Statistics (IBGE). Regional concentration indexes were calculated from charcoal production data obtained from native forests (in tons) in the state, at mesoregion, microregion, and municipal levels.

The total production scenario and the participation of mesoregions, microregions and municipalities were analyzed using a timeframe ranging from 1990 to 2017. In addition, the Geometric Growth Rate (GGR), calculated according to equation 1, was used to evaluate the changes (gains and losses) in charcoal production within Pará at each regional level (Junior et al., 2019).

$$GGR(\%) = \left[\sqrt[\Delta t]{\frac{V_F}{V_0}} - 1 \right] * 100 ....(1)$$

Where, VF is the charcoal production for the end of the year, at t; V0 refers to initial year values; Δt is the production temporal variation (in years).

Concentration and inequality measures

The following indexes were used to examine charcoal market concentration in the state of Pará: Bain Concentration Ratio (CR(k)), Herfindahl-Hirschman Index (HHI), Theil Entropy Index (EI), and Gini Index (G), as proposed by Junior et al. (2019).

The concentration ratio (CR(k)) proposed by Bain (1959) analyses the market shares of k (where k = 1, 2, ..., n) charcoal producing regions in Pará, according to equation 2.

$$CR(k) = \sum_{i=1}^{n} Si \text{......................................(2)}$$

where CR(k) is the concentration ratio of k regions, Si is the market share of the amount of charcoal produced as a percentage of region i (municipalities, microregion).

As suggested by Bain (1959), we used the four main regional producers, [CR (4)] and the eight [CR (8)] municipalities and microregions to determine the production concentration. Additionally, we also included the participation of 20 [CR (20)] and 30 [CR (30)] major native charcoal producers in the municipalities.

The HHI (equation 3) is used to determine the regions' (municipalities, microregion, and mesoregion) participation in the charcoal production of the state.

$$HHI = \sum_{i=1}^{n} Si^2 \text{...(3)}$$

Where, n is the number of regions producing native charcoal (municipalities, microregion and mesoregion) and Si is the market share of the amount of native charcoal produced in the state as a percentage of region i (municipalities, microregion and mesoregion). The index value varies between zero, indicating equal participation or the same expression for production in each region, and one, which indicates maximum concentration.

The EI proposed by Theil (1967) represents the inverse concentration (equation 5) and seeks to verify the inequality between regions given the heterogeneity of production regions.

$$EI = - \sum_{i=1}^{n} \ln (Si) \text{...................................(4)}$$

Where n is the number of regions producing native charcoal (municipalities, microregion and mesoregion), Si is the market share for the amount of native charcoal produced in Pará as a percentage of region i (municipalities, microregion and mesoregion); ln=natural logarithm. The EI measures the inverse concentration of HHI and ranges from 0 (maximum concentration) to 1n (n) (minimum concentration).

The Gini Coefficient (G) is used to measure the degree of inequality of charcoal production in the regions. This index is an additional tool for the concentration coefficients, since concentration implies higher inequality. The index is calculated using equation 5.

$$G = 1 - \frac{\sum_{i=1}^{n}(Sij + Si)}{n} \text{...................................(5)}$$

Where n is the number of regions producing native charcoal in the State (municipalities, microregion and mesoregion), Sij is the accumulated portion (j) in region I (municipalities, microregion and mesoregion) for the amount of native charcoal

produced in Pará, and Si is the market share of the amount of native charcoal produced in Pará as a percentage of region i (municipalities, microregion and mesoregion).

The G index varies from 0 to 1, being classified as follows: 0.101 to 0.250 means inequality from zero to weak; 0.251 to 0.500 indicates it is weak to medium; 0.501 to 0.700 indicates it is medium to strong; 0.701 to 0.900 indicates it is strong to very strong; and 0.900 to 1.000 indicates very strong to absolute inequality (Junior et al., 2019)

Results and discussion

Native forest stocks, which can be linked to several factors such as unsustainable logging, large-scale livestock, illegal timber production and marketing, road opening, infrastructure projects, migration, and expansion of the agricultural border (Barros and Veríssimo, 2002; Banco Mundial, 2003; Hecht, 2012; Girard, et al., 2014; Becker, 2016; Fearnside, 2017).

Homma et al., (2006) developed a study on charcoal production in the Amazon and pointed to its production and use as responsible for rainforest destruction since 1988. For these researchers, the "Guseiras" (companies that produce pig iron) became one of the greatest environmental hazards, as they function within the Arc of Deforestation with no concern for the basic supply input (firewood and/or wood for charcoal production), taking resources from nature in a predatory manner.

Amaral (2011) argues that the implementation of steel industries in the Amazon pushed charcoal production towards other geographical areas in order to obtain more advantageous conditions for pig iron production and reproduction. The implementation of these industries promoted a form of monopolization and led these areas to produce charcoal intensely, with low costs and no social and environmental concern.

According to Tacconi et al., (2019), the establishment of laws and regulations to fight environmental crimes has been one of the most modern and comprehensive strategies to reduce deforestation in the Amazon and, consequently, to reduce supply of raw materials for charcoal production. Girard et al. (2014) argue that monitoring working conditions has contributed to the reduction of deforestation rates. According to the authors, both wood and charcoal production are linked to slave labor since they are illegal and require low-skilled manual labor.

From 1990 to 2017, Southeast Pará was the largest charcoal producer in all studied years, due to the steel pole (Figure 2). This is clearer in the survey conducted by the National Institute for Space Research (INPE) in 2000–2001, in which a temporal study of the period identified the loss of approximately 15.7% of the Legal Amazon in the

states of Mato Grosso, Pará, and Rondônia. The report shows that the loss of forest cover has reached 80–90% of their total surface area in some municipalities of this state. In Pará, this region is entirely and geographically located in the Arc of Deforestation.

In the period from 1996 to 2004, the state was at the peak of logging, without any legal and environmental criteria, and in addition to that, the implantation of the sidergurico pole in the region. Thus, forcing the production of charcoal in that period. In 2004, inspection began, which represents a drop in production. And in the following year, this production has a slight increase, corresponding to

legal production. Northeastern Pará ranked second in the analyzed period. The Lower Amazonas mesoregion, and the metropolitan areas of Belém and Marajó, had a low contribution in the state context, and were not graphically represented. This is because more productive activities in the Lower Amazon, for example, are linked to the services sector, the municipality of Santarém, mining, agribusiness, family farming and, to a lesser extent, tourism (Gomes and Andrade, 2011; Barbosa et al., 2012), and that currently persists. The main economic activities in the metropolitan region are not defined as they exhibit the greatest dynamism and diversification in the state..
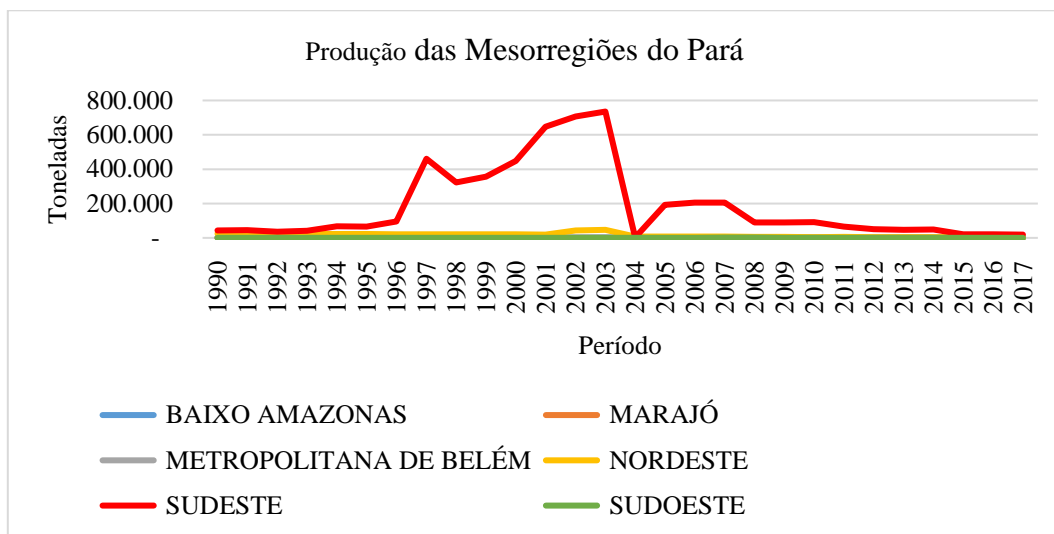

Figure 2: Evolution of charcoal production in tons (t) in mesoregions of the state of Pará from 1990 to 2017
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The concentration ratio (Figure 3) of charcoal production in Pará between 1990 and 2017, considering the destination after production, shows the behavior of the four largest [CR(4)micro] and the eight largest microregions [CR(8)micro] for charcoal production. A total of 22 microregions were observed during this study period, with the four largest accounting for 88.57% of production, characterizing an extremely concentrated market according to Bain's classification (1959), facilitating inspection and trade.

The highest accumulated production in the state was recorded in 2003 (15.23%) and the lowest in 2004 (0.07%). The charcoal producing microregions with highest concentration in 2003 were Paragominas, Tomé-Açu, Tucuruí and Guamá, respectively, explained by the large number of forestry companies in the State of Pará. In 2004, the lowest accumulation year, Guamá, Cametá, and Tomé-Açu, located in the Northeast, and the Óbidos mesoregion, in the Lower Amazonas region produced the most charcoal. During the period analyzed in this study, the microregion of Paragominas alone was responsible for 76% of

lumber production, which helps in the production of coal (IBGE, 2019).

According to Stone's observations (1989), only the municipality of Paragominas showed 80% exponential growth of wood production by vertically integrated industries until 1988, that is, the exploitation and processing were conducted by the companies themselves. According to IMAZON (2002), in the 1970s and 1980s, logging in northern Brazil became valued as a result of timber scarcity in southern Brazil and in Asian tropical forests. Added to the accessibility of the Amazon at that time, enabled by the Belém-Brasília integration region, this scenario became the stage for the strong timber production that had occurred since 1965 (Oliveira et al., 2012). At that time, the established companies held only 15% of the explorable areas, while 61% of the production was purchased through exploration rights in agricultural areas until the scenario changed as forests became more appreciated.

The concentration ratio of the eight largest microregions [CR (8)micro] was on average 97.30% for the period, which, according to Bain (1959), is an extreme level of production. The highest CR (8)micro concentration was 13.71% (2003) and the lowest was 0.23% (2004). The eight microregions in

which production was concentrated in 2003, the year with highest production level, were: Paragominas, Tomé-Açu, Tucuruí, Guamá, Cametá, Óbidos, Bragantina, and Santarém, respectively. The

microregions included in CR8 in 2004 were: Guamá, Cametá, Tomé-Açu, Óbidos, Bragantina, Altamira, Paragominas, and Castanhal.
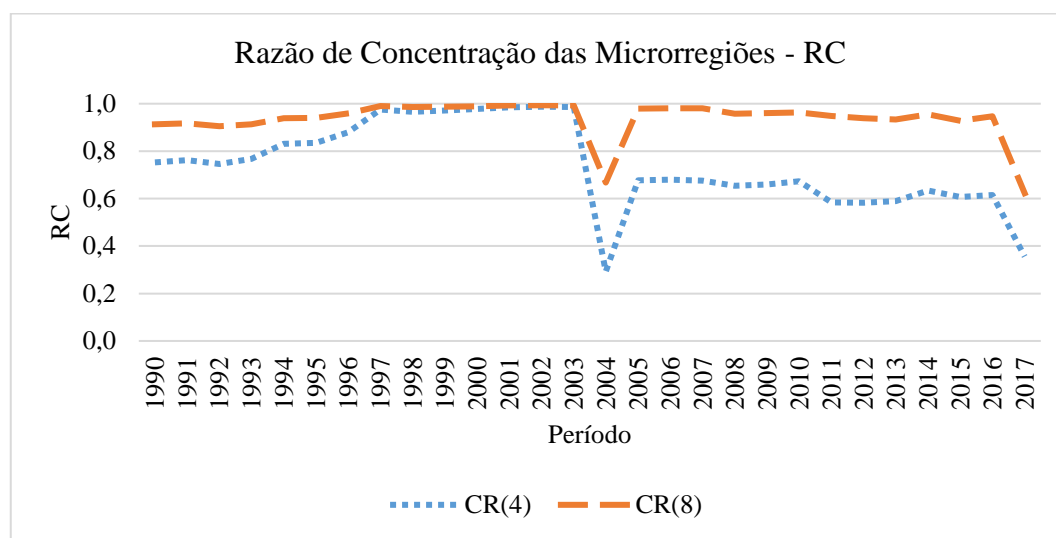

Figure 3 Evolution of Concentration Ratio [CR(k)] of charcoal production in microregions of Pará
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The production concentration ratio per municipality (Figure 4) was observed for 144 locations from 1990 to 2017. The four largest production volumes in this period are responsible for 64.74% of the production, which, according to Bain (1959), is a high concentration. The highest concentration occurred in 2003 (13.27%) and the lowest was recorded in 2004 (0.22%). The municipalities that contributed the most in 2003 were: Paragominas, Dom Eliseu, Itupiranga, and Rondon do Pará. The municipalities with the highest production in the least productive year (2004) were: Paragominas, Dom Eliseu, Ulianópolis, and Rondon do Pará.

The concentration ratio of the eight largest charcoal producing municipalities [CR (8)mun] was on average 75.91% in the studied period, which is an extreme concentration according to Bain's classification (1959). The municipalities with the highest production levels were: Paragominas, Dom Eliseu, Itupiranga, Rondon do Pará, Marabá, Ulianópolis, Tailândia, and Eldorado do Carajás.

Municipalities that make up the CR(20)mun were: Paragominas, Dom Eliseu, Itupiranga, Rondon do Pará, Marabá, Ulianópolis, Tailândia, Eldorado do Carajás, Moju, Breu Branco, Novo Repartimento, Abel Figueiredo, São Geraldo do Araguaia, Parauapebas, Tucuruí, Jacundá, Nova Ipixuna, São Domingos do Araguaia, Abaetetuba and Goianésia do Pará, respectively. The concentration of the 30 largest charcoal producing municipalities [CR(30)mun] in Pará was 95.48% throughout the period.

Oliveira et al., (2012) state that some obstacles such as high transportation costs and

effective action by environmental monitoring agencies were responsible for the reduced availability of the main raw material of the timber sector. As a result, these factors established a crisis scenario in this region. Such phenomena are known as "economic boom-collapse," since the initial years experienced an accelerated growth (boom) followed by a strong decline in income, employment, and availability of raw materials (collapse) (Oliveira et al., 2012).

Gomes (2010) cites Paragominas in the state of Pará as a typical example of this phenomenon as this town's economy is dependent on logging. This region suffered a severe crisis in the late 1990s and early 2000s. However, the scenario was modified soon after (2008) and Paragominas was considered the most deforested municipality in Brazil and is therefore subject to monitoring by "Operation Arc of Fire."

These inspection actions, which were correct, changed the scenario of wood production in the State of Pará. Since many municipalities considered to be timber poles have lost this function and the production of charcoal is mostly clandestine, and this charcoal produced is sold internally, without effective market control policies and without any scientific technical specification.

Concentration on production can have both benefits and harms. Because concentrated production can facilitate inspection, legalization and trade, however, greater pressure on forest resources present in certain municipalities can lead to deforestation. Another issue of non-concentration is the diversification of species used in charcoal production in the different municipalities of the state, which reflects the creation of a policy of

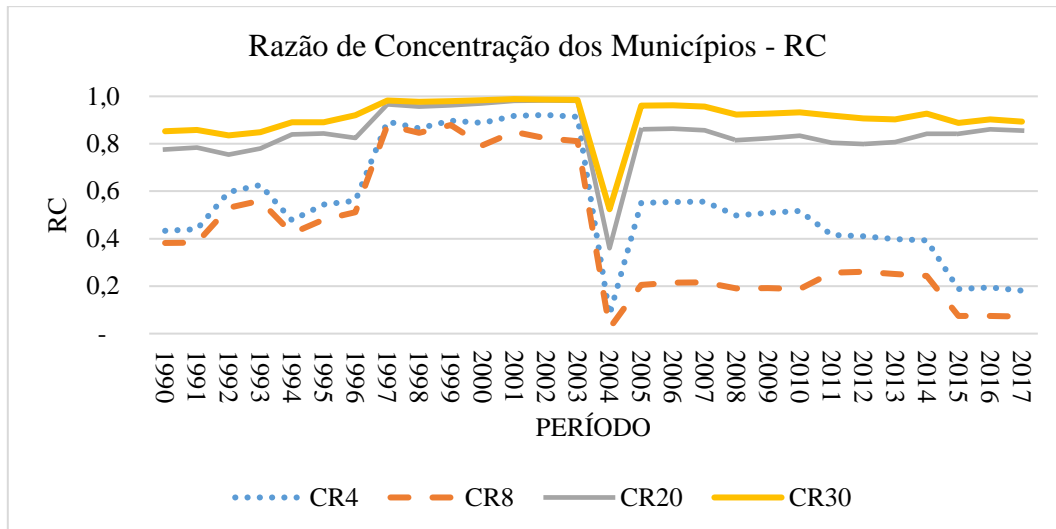identification, legislation and monitoring of charcoal production.

Figure 4 Evolution of Concentration Ratio (CR(k)) of charcoal production in Pará State municipalities

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The HHI index for the charcoal production in Pará (1990 to 2017; Figure 5) was heterogeneous over time when applied to all levels, that is, sometimes poorly concentrated, sometimes very concentrated. However, the HHI applied to municipalities (HHImun) and microregions (HHImicro) resulted in lower concentrations compared to mesoregions (HHImeso), which presented higher concentration and lower competition among regions.

From 1990 to 1997, the HHImun increased due to the reduced number of producing municipalities. From 1998 onwards, the reduced number of charcoal producing municipalities led to a higher production concentration up to 2003. In 2004, production abruptly approached the lowest production value recorded, indicating market homogeneity, in contrast with the previous condition (shifting from a high concentration to even more competitive production among municipalities). The following year returned to a concentrated market and this scenario continued up to 2017. This behavior is explained by the energy policy measures and the successful contribution of command and control institutions, which encourage sustainable land use (CEPAL et al, 2011).

The HHImeso analysis presented the highest average (0.7401) among the studied levels, indicating, in general, a highly concentrated market for the mesoregions in Pará. The difference among the indicators was on average 0.1253. The HHImicro was on average 0.3960. However, a high concentration period was recorded before 2003, becoming only concentrated after 2005. This decline is a consequence of the debate on increasing the value of forests by the Reduction of Emissions from Deforestation and Forest Degradation (REDD+), to reverse decentralization tendencies, and promote a recentralization of forest governance (PHELPS et al., 2010).

The concentration is considered as moderate among the municipalities with an average HHImun value of 0.2188, but also presents heterogeneous behavior in the period. According to VIANA et al. (2012), in Pará, the end of the 1990s is marked by the scarcity of raw materials for the timber industry, and the destination of a good part of this raw material was the production of charcoal As such, the population had to undergo a redefinition process and choose other economic alternatives. In 1995, the scenario was a new economic cycle, where farmers, supported by municipal and state governments, and by agricultural research institutions and extensionists, invested in an experimental soybean field that later led to Paragominas becoming the center of grain production (PARAGOMINAS, 2012).
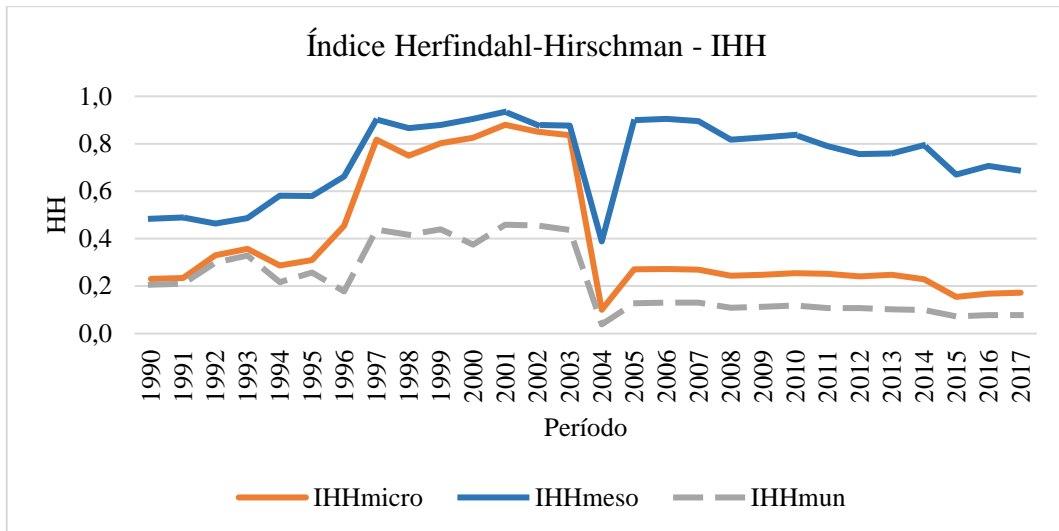
Figure 5: Evolution of Herfindahl-Hirschman Index for charcoal producing regions in Pará (Municipalities, Microregions and Mesoregions levels)

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Legal factors contributed substantially to the reduced charcoal production. In 2007–2008, INPE detected a new increase in deforestation rates in the Amazon, motivating the federal government to react by means of a series of political measures.

In early 2008, the government took actions such as the promulgation of Presidential Decree 6321/2007 and Ordinance of the Ministry of the Environment No. 28 of 2008, highlighting the fight against deforestation (Guimarães et al., 2011). These instruments targeted the municipalities that made up the red list.

The EI progress for charcoal production in Pará from 1990 to 2017 (Figure 6) indicates that its application at municipality and microregion scales presented an extreme approximation, with only a 0.3821 difference. However, different scales appeared at the mesoregion level (on average 2.5713), being considered the farthest scale from 0 when compared to the other levels. From 2005 onwards, all levels show a gradual tendency toward monopoly, where only one municipality legally produced charcoal.
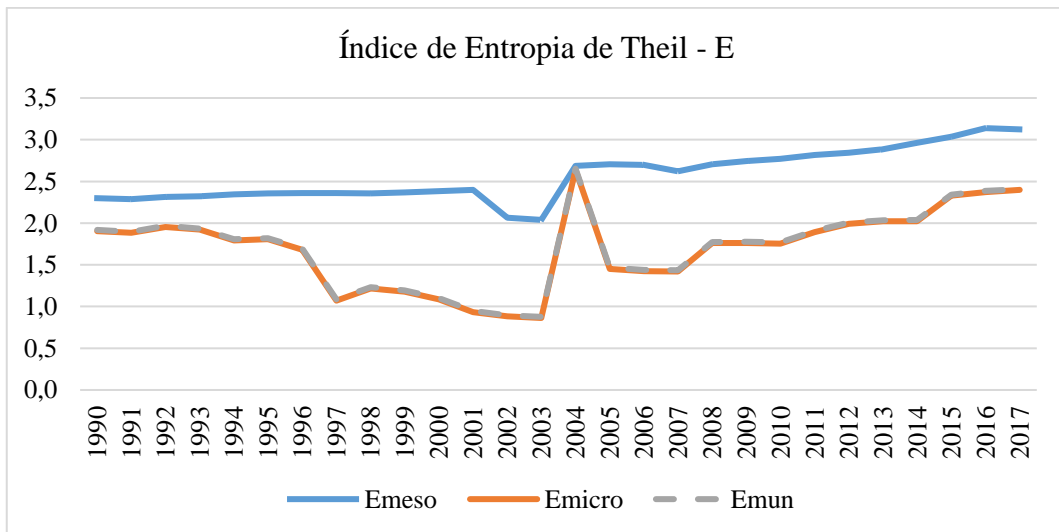

Figure 6 Evolution of Entropy Index (EI) for charcoal production in Pará (regional levels)

The Gini Index (G) for charcoal production in Pará (Figure 7) showed a very strong to absolute inequality in all regional levels during the investigated years, except for 2004. There was a change in classification for Gmeso and Gmicro. Gmeso presented a null-to-weak classification in 2004, returning to a very strong to absolute inequality in 2005. In the case of Gmicro, the inequality showed an unexpected behavior, changing market inequality from weak to zero or even nonexistent in a single year. The index applied to the

municipalities (Gmun) was considered very strong to absolute throughout the period.

Gmicro was on average 0.8335, which ranks the inequality at this level as strong to very strong. Its variance during the period was 0.02711. The highest inequality was in 1990 (0.9091), while the lowest (0.091) occurred in 2004. Similarly, Gmeso was on average 0.8925 (between strong and very strong), with a variance of 0.0292. The highest inequality was recorded in 2001 (0.3435), while the lowest was in 2004 (0.0705). Gmun was on average 0.9937 and had a variance of 0.000032, which ranks inequality as very strong to absolute. The highest inequality was recorded in 2001 (0.9995), while 2004 exhibited the lowest inequality index (0.9707).
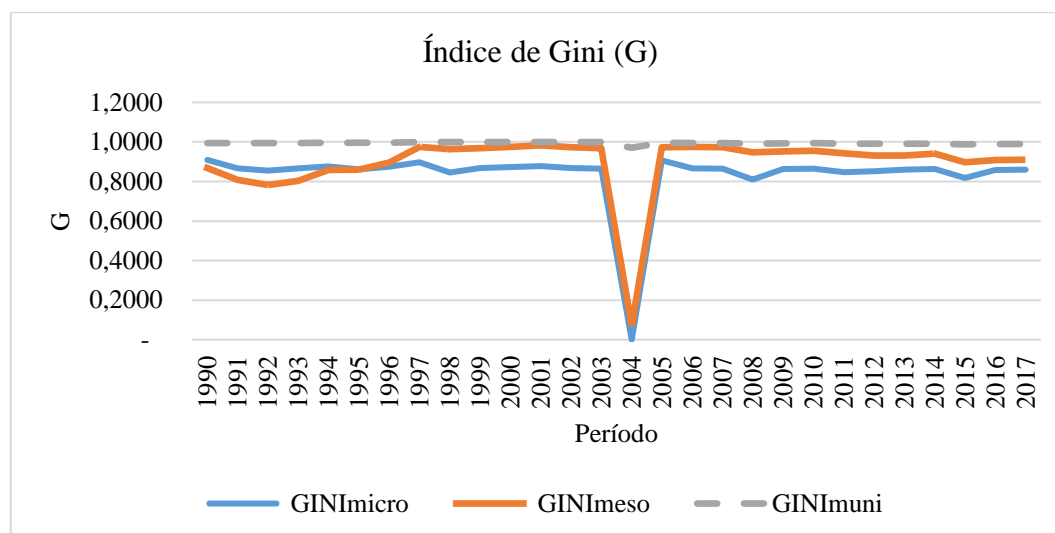

Figure 7 Gini Index (G) for charcoal production in Pará.

Following a history marked by intense use of natural resources anchored in the occupation and development of the Amazon, from 2004 onwards, the federal government assumed a strategy markedly concerned with the future of this region. Both Viana et al. (2012) and IBGE (2018) argue that the most significant initiative established by environmental policies was the release of the Action Plan for Preservation and Control of Deforestation of Brazilian Legal Amazon (PPCDAM). This plan marked the beginning of a new environmental history, based on a set of policies structured around three main objectives, that is, land regularization, monitoring land use changes, and incentives for sustainable activities. (Barreto and Araújo, 2012). And the charcoal production activity is considered predatory, this activity has been reduced to the minimum legally possible, but it remains strong illegally.

Conclusions

After these discussions, the indicators used showed a reduced concentration from 2004 onwards, which provides good evidence of the charcoal market structure in Pará.

Despite a trend toward dispersal, production is concentrated in the Southeast of the state, mainly in the microregion of Paragominas since it covers the two most active municipalities in terms of logging (Paragominas and Rondon do Pará).

We also emphasize that according to the CR(k) values, the competition between municipalities takes several forms over time. However, for most municipalities, it displays high concentration, building a monopolistic market structure in the studied period.

Finally, the HHI showed concentrating tendencies for the market in the regional levels studied, especially when analyzing the mesoregions. EI certifies the HHI analysis, indicating concentration similarity between the regional levels of charcoal production in the state, with significant changes at the mesoregion level. The mean G showed strong to very strong inequality for municipalities, microregions, and mesoregions due to the disparity of some municipalities.

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