Ciência Rural, Santa Maria, v.52:10, e20200357, 2022 http://doi.org/10.1590/0103-8478cr20200357

ISSNe 1678-4596
FORESTRY SCIENCE

Regional concentration of native fuelwood production in Rio Grande do Norte, Brazil (1990–2017)

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ABSTRACT: *This paperexamined the regional concentration of native fuelwood production in Rio Grande do Norte, Brazil, between 1990–2017. Information on native fuelwood was gathered fromforestry activitiescollected by the Brazilian Institute of Geography and Statistics (IBGE). This studyanalyzed the current situation and the spatial distribution of the state's fuelwood production by quartiles. The following indicators were used to measure market concentration: Gini Coefficient (G), Comprehensive Concentration Index (CCI), Herfindahl-Hirschman Index (HHI) and Concentration Ratio [CR(k)]. In Rio Grande do Norte, there was a -2.76% annual decrease in the production of native fuelwood, from 5,280 x10³ m³ (1990) to 777 x10³ m³ (2017). Classification of the municipalities by quartile revealed that most municipalities had low fuelwood production. The G inferred a very strong to absolute inequality for the municipalities and a weak to null inequality for the mesoregions.The CCI demonstrated no market concentration in the municipalities and a regional concentration in the mesoregions. The HHI corroborated the CCI by affirming the presence of a competitive market for the municipalities and microregions and a concentrated market in the mesoregions.The CR(k) of the four largest municipalities indicated a moderately low concentration. This study concluded that there is a competitive market structure for native fuelwood inthe state of Rio Grande do Norte.*
Key words: *forest economy, bioenergy, Caatinga, semi-arid.*

Concentração regional da produção de lenha nativa no Rio Grande do Norte, Brasil (1990-2017)

RESUMO: *Este artigo analisou a concentração regional da produção de lenha nativa do Rio Grande do Norte - Brasil, no período de 1990 a 2017. As informações da lenha nativa foram obtidas da produção da extração vegetal e da silvicultura, disponíveis no Instituto Brasileiro de Geografia e Estatística (IBGE). Analisou a conjuntura, a distribuição espacial da produção de lenha estadual por meio os quartis e mensurou a concentração por meio dos indicadores: Coeficiente de Gini (G), Índice de Concentração Compreensiva (CCI), Índice de Herfindahl-Hirschman (HHI) e Razão de Concentração [CR(k)]. Os resultados mostraram que houve decréscimo de -2,76% a.a. na produção de lenha nativa estadual, partindo de 5.280 x10³ m³ (1990) para 777 x10³ m³ (2017). O quartil municipal revelou que a maioria dos municípios produz pouca lenha; apesar do G ter inferido uma desigualdade muito forte a absoluta para os municípios produtores de lenha e fraca a nula para as mesorregiões, já o CCI mostrou para os municípios que é não concentrado e as mesorregiões tem concentração regional; HHI corroborou com esta afirmação mostrando um mercado altamente competitivo para os municípios e microrregiões e concentrado para as mesorregiões produtoras de lenha; o CR(k) dos quatro maiores municípios foi constatada uma concentração moderadamente baixa. Conclui-se que a lenha nativa do estado do Rio Grande do Norte possui estrutura de mercado competitiva.*
Palavras-chave: *economia florestal, bioenergia, caatinga, semiárido.*

INTRODUCTION

Since the beginning, forest biomass has been a source of renewable energy to meet man's needs. Fuelwood shows potential as a clean, renewable energy resource that generates employment and local income throughout Brazil (SOARES et al., 2006). In 2017, Brazil produced 77,044x10³ m³ of fuelwood: 72.06% from forestry and 27.93% from vegetation extraction. Fuelwood production derived

Received 04.20.20 Approved 11.16.21 Returned by the author 02.12.22
CR-2020-0357.R4
Editors: Leandro Souza da Silva Rômulo Trevisan

from forestryis distributed throughout the South (64.05%), Southeast (24.32%), Midwest (9.02%), Northeast (2.27%), and North (0.33%), and fuelwood derived from extractivismis distributed throughout the Northeast (58.35%), North (10%), South (9.7%), Midwest (8.32%), and Southeast (2.55%) (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE, 2019).

The Northeast is dependent onvegetation extraction (fuelwood and charcoal) as the primary energy resource for domestic, commercial and industrial purposes. In 2017, the mainstates producing fuelwood were Ceará [3,013 x10³ m³], Bahia [2,485 x10³ m³] and Maranhão [1,920 x10³ m³]. Rio Grande do Norte (RN) produced 777 x10³ m³ of fuelwood derived from vegetation extraction (BRASIL, 2018; IBGE, 2019). In addition to the other states covering Brazil's semi-arid region (Caatinga biome), RN's energy grid depends on forest resources and fuelwood isthe main resource supplying redware factories in the state's Seridó region (NASCIMENTO, 2011).

Industrial concentration, an economic activity, is one of the most important components of competition between firms. Concentration and competition are related inversely: as concentration intensifies, the competition level in the market declines (POSSAS, 1999). Additionally, concentration indicators provide empirical elements that explain supply and demand, the degree of product differentiation, and market entry conditions, among others (RESENDE, 1994; RESENDE& BOFF, 2002).

Market studies and regional analyses have recommended tests that apply market concentration to the forest sector. From the international scenario, COELHO JUNIOR et al.(2013) investigated the exportation of forest products and COELHO JUNIOR et al. (2018a) examined pulp exports. Considering Brazil, SIMIONI et al. (2017) assessed the progress and concentration of fuelwood and charcoal production derived from forestry. COELHO JUNIOR (2016) examined pine nut production in Paraná. MARTINS et al. (2018) observed the disparity of vegetation extraction in the Northeast. COELHO JUNIOR et al. (2018) researched fuelwood in Paraíba,while COELHO JUNIOR et al. (2019) analyzed charcoal in Paraíba.

Considering the need to understand the fuelwood market in RN and the state's market structure, this study analyzes the regional concentration of native fuelwood production in RN between1990–2017.

MATERIALS AND METHODS

Information on the production of native fuelwood (m³) in RN is provided in the data on Forestry Activities (PEVS) collected by the IBGE. The data was analyzed for the period between 1990–2017. Observations of the state of RN were based on geopolitical segments: municipalities, microregions, and mesoregions.

The mesoregions were observed for 1990, 1995, 2000, 2005, 2010, 2015, and 2017 to analyze the current native fuelwood production in RN. The spatial distribution of production inthe municipalities and microregions was examined by quartiles (Q_k) for 1990, 2000, 2010 and 201 $Q_k = \frac{k \sum f_i}{4}$, where k = quartile order number and = $\sum f_i$ sum of the native fuelwood production in the RN region (municipalities and microregions). Fuelwood production was classified intothe following quartiles by regional level (municipality and microregion): Low – firstquartile (Q1) was 0% < Q1 ≤ 25%; Medium– second quartile (Q2) was 25% < Q2 ≤ 50%; High – thirdquartile (Q3) was 50% < Q3 ≤ 75%; and Very High – fourthquartile (Q4) was 75% < Q4 ≤ 100%.

The geometric growth rate (*GGR*) was used to evaluate changes (gains and losses) in thenative fuelwood production of RN in the regional segments: $GGR[\%] = \left[\sqrt[\Delta t]{\frac{V_F}{V_O}} - 1\right] * 100$, where V_F is the fuelwood production for the final year in *t*; V_0 refers to the values for the initial year; Δt is the temporal variation of production (expressed in years) (CUENCA& DOMPIERI, 2017). The following indicators were used to measure concentration: Gini coefficient, Comprehensive Concentration Index, Herfindahl-Hirschman index, and Concentration Ratio.

The Gini Coefficient (*G*) is a measure of inequality developed by Gini (1912). This coefficient was originally indicated to measure income inequality. However, it can also measure the degree of inequality within an industry or production: $G = 1 - \frac{\sum_{i=1}^{n}(s_{ij} - s_i)}{n}$, where n = number of fuelwood-producing regions in RN; S_{ij} = cumulative share of the amount of fuelwood produced in ascending order; S_i = market share percentage of region *i*(municipalities, microregions, and mesoregions) in the fuelwood production of RN. *G* varies between 0 and 1 and can be classified asnull to weak (0.10 < G ≤ 0.25), weak to medium (0.25 < G ≤ 0.50), medium to strong (0.50 < G ≤ 0.70), strong to very strong ($0.70 < G \leq 0.90$) and very strong to absolute ($0.90 < G \leq 1.00$).

Proposed by Horvarth (1970), the Comprehensive Concentration Index (*CCI*) measures relative and absolute dispersion: $CCI = S_1 + \sum_{i=2}^{n} S_i^2 \left(1 + (1 - S_i)\right)$, where S_1 is the largest market share among fuelwood producers in a region (municipalities, microregions, and mesoregions). $\sum_{i=2}^{n} S_i^2 \left(1 + (1 - S_i)\right)$ represents the sum of the squares of each region's proportional sizes, and a weighted multiplier was applied to reflect the rest of the state. A *CCI* equal to 1 indicates a monopolistic condition, indicatinghigh concentration.

The Hirschman-Herfindahl Index (*HHI*) was originally claimed by HIRSCHMAN (1964); although, the creators Hirschman and Herfindahl developed the indicator independently: $HHI = \sum_{i=1}^{n} S_i^2$, where S_i = market share percentage of region *i* (municipalities, microregions, and mesoregions) in the fuelwood production of RN and*n* = number of participants in fuelwood production in region *i*. The index varies between *1/n* (no concentration) and 1 (maximum concentration), indicating a monopolistic situation. For intertemporal comparative analyses that contemplate entering and exiting participants, RESENDE (1994) suggested the adjusted Hirschman-Herfindahl Index (*HHI'*): $HHI' = \frac{1}{n-1}(nHHI - 1); n > 1$ The *HHI'* lies in an interval between 0 and 1 (monopoly); therefore, market concentration increases as the value moves away from zero and is classified as follows (RESENDE& BOFF, 2002): competitive market ($HHI' < 0.1$), unconcentrated market ($0.10 \leq HHI' < 0.15$), moderate concentration ($0.15 \leq HHI' \leq 0.25$), and high concentration ($HHI' > 0.25$).

The Concentration Ratio [*CR(k)*] is the sum of the *k* (where *k* = 1, 2, ..., *n*) number of regions and firms in the market (BAIN, 1959): $CR(k) = \sum_{i=1}^{k} S_i$, where *CR(k)* = the concentration ratio of k regions (municipalities and microregions) producing native fuelwood and S_i = market share percentage of the region *i* in the fuelwood production of RN. According to Bain's classification (1959), the four largest [*CR(4)*] and eight largest [*CR(8)*] municipalities and microregions were evaluated. Additionally, the behavior of the 20[*CR(20)*] and 30 [*CR(30)*] largest fuelwood-producing municipalities in RN were observed (COELHO JUNIOR et al., 2013).

RESULTS AND DISCUSSION

Table 1 shows the progress of fuelwood production derived from vegetation extraction in the mesoregions of RN for 1990, 1995, 2000, 2005, 2010, 2015, and 2017. Fuelwood production was 5,280 x10^3 m³ in 1990, and it was 777 x10^3 m³ by 2017, representing an average annual decrease of -2.76%, lower than in the northeastern region (-3.82% per year) (MARTINS et al.,2018). This retraction of forest extractivism was attributed to the scarce availability of forest resources due to agricultural and urban expansion and greater inspection by environmental agencies (COELHO JUNIOR et al., 2018). Prior to 2000, the Central Potiguar mesoregion led the state ranking, and the Oeste Potiguar mesoregion assumed hegemony over native fuelwood as of 2000. The Agreste Potiguar mesoregion had the biggest fall in GGR (-12.38% per year), followed by the Oeste Potiguar (-8.76% per year), Central Potiguar (-5.56% per year), and Leste Potiguar (-5.15% per year) mesoregions. Based on the spatial distribution of fuelwood production in northeastern Brazil, COELHO JUNIOR et al. (2018b) observed that the state of RN is among the largest producers of fuelwood from vegetationextraction per km². Coelho Junior, Martins, and Carvalho (2018) quantified the impacts of burningnative fuelwood in northeastern Brazil and reported that RNwas among the highest emitters of carbon dioxide equivalent per area (kg CO_2-eq./km²).

Figure 1 represents the spatial distribution of fuelwoodproduction from vegetation extraction in the microregions and municipalities of RN for 1990, 2000, 2010, and 2017 by quartiles. Figure 1.a. showed that the Seridó Oriental microregion had very high fuelwood production in 1990 (Q4), equivalent to 750m³ - 1,001m³ of fuelwood. In 2000 (Figure 1.c.), the Litoral Sul, Pau dos Ferros, Chapada do Apodi and Borborema Potiguar microregions were in Q4. In 2010 and 2017 (Figure 1.e. and Figure 1.g.), only Pau dos Ferros was in Q4. About 50% of the microregions had low fuelwood productivity (Q1) in the years presented in figure 1. The following Q1 municipalities participated at least once in the period under analysis: Mossoró, Governor Dix-Sept Rosado, Caraúbas, Marcelino Vieira, São Miguel, Alexandria, Caicó, Parelhas and Carnaúba dos Dantas.

Figure 2 shows the progress of fuelwood production in RN from 1990–2017 based on the *G* and the *CCI*. The mean values for *G* (Figure 2.a) demonstrated a very strong to absolute inequality (0.9697) for the municipalities (G_{Munic}), a strong to very strong inequality (0.7809) for the microregions (G_{Micro}) and a weak to medium inequality (0.3083) for the mesoregions (G_{Meso}). The inequality of native fuelwood production in RN is more significant

Table 1 - Evolution of the quantity of firewood produced in the mesoregions of Rio Grande do Norte - RN, in thousand cubic meters ($x10^3$ m^3) for 1990, 1995, 2000, 2005, 2010, 2015 and 2017.

Mesorregions	1990	1995	2000	2005	2010	2015	2017
Potiguar Central	2.081,36	1.892,03	248,30	257,12	228,24	238,14	171,56
West Potiguar	2.036,55	1.591,07	846,99	1.001,65	796,61	568,69	444,79
East Potiguar	606,61	513,21	332,04	94,35	26,14	7,31	15,70
Agreste Potiguar	555,83	424,21	329,37	226.07	158,77	165,04	145,46
Rio Grande do Norte	5.280,36	4.420,53	1.756,71	1.579,21	1.209,78	979,19	777,55

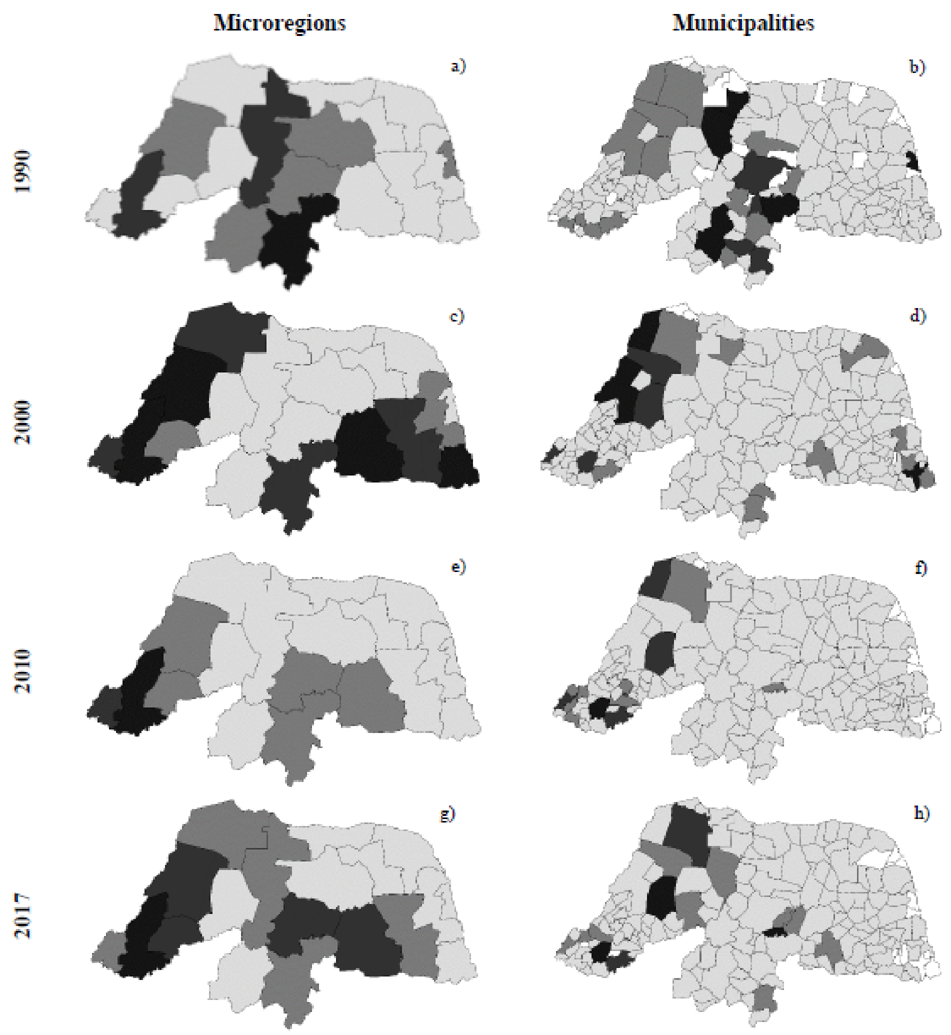
Source: IBGE (2019).

compared to Paraíba (COELHO JUNIOR et al., 2018), as they are neighboring states in the Caatinga biome with the same forest management practices. The *CCI* (Figure 2.b) presented a peculiar characteristic at regional levels, resulting in a high concentration (CCI_{Meso} = 0.7007) despite the weak to medium inequality in the mesoregions when associated with *G*. G indicated a high inequality in the municipalities (CCI_{Munic} = 0.1015) and microregions (CCI_{Micro} = 0.3036). However, the market was not characterized as a concentrated market.

Figure 3 shows the progress of fuelwood production in RN from 1990–2017 based on the Herfindahl-Hirschman Index (*HHI*). Although, the other indicators demonstrated different behaviors between the regions, the municipal *HHI* (HHI_{Munic}) and microregional *HHI* (HHI_{Micro}) exhibited behaviors similar to those seenin figures 3.c. and 3.b., respectively; thus, demonstrating an unconcentrated market. Figure 3.a. illustrates the mesoregional *HHI*(HHI_{Meso}), indicating the concentration trends relative to the lower limit (LL). Since 2000, the HHI_{Meso} has distanced it self from the LL, indicating an increase in market concentration, with a mean HHI_{Meso} of 0.3903 and a LL of 0.25 in the analysis period. For the microregions and municipalities, the *HHI* approached the *LL*and revealed a low concentration, resulting in a mean HHI_{Micro} of 0.097 for the microregionsand *LL* of 0.052 between 1990–2017 (Figure 3.b). The difference between the HHI_{Micro} and the *LL* was greater in 2013 (0.072). In 2001, the difference was smaller (0.026). At the municipal level, the mean $HHI_{Munic}$was 0.0206, and the *LL*was 0.0064 for the period in question. Figure 3.d depicts the *HHI* for the three regional segments. The HHI_{Meso} presented an unconcentrated market structure (*HHI'*<0.15) until 1997. Additionally, there was a moderately concentrated displacement due to increased production in the Oeste Potiguar mesoregion until the end of the analysis period. Nevertheless, the HHI'_{Munic} and HHI'_{Micro} remained very close and presented stable behaviors thanthe HHI_{Meso}, demonstrating a competitive market. COELHO JUNIOR et al. (2018) analyzed the HHI_{Meso} forfuelwood production in Paraíba, and the indicator presented more stability in a moderately concentrated market.

Figure 4 shows the CR(k) of fuelwood production in themicroregions and municipalities of RN from 1990–2017. According to BAIN's classification (1959), the mean $CR(4)_{Micro}$ was 50.94%, indicating a moderately high concentration in the state's fuelwood production (Figure 4.a.). The highest concentration was registered in 2013 (63.08%), while the lowest was in 2001 (42.02%). Throughout the period in question, the $CR(4)_{Micro}$ presented a moderately low concentration with no changes in the concentration pattern. As reported by COELHO JUNIOR et al. (2018), the behavior of the CR(k) forfuelwood production in Paraíba was similar to that of RN. The microregions of RN that contributed the most to the $CR(4)_{Micro}$ were Pau dos Ferros, Chapada do Apodi, and Serra de São Miguel. The mean $CR(8)_{Micro}$of RN was 77.38%, indicating a moderately high concentration, with the highest concentration recorded in 2013 (85.94%) and the lowest recorded in 1990 (69.99%). The following microregions contributed at least once to the $CR(8)_{Micro}$: Seridó Oriental, Vale do Açu, Pau dos Ferros, Serra de Santana, Litoral Sul, Chapada do Apodi, Borborema Potiguar, Serra São Miguel, Umarizal, Seridó Ocidental, Serra Santana, Angicos, Natal, Agreste Potiguar and Mossoró.

The mean Concentration Ratio of the four [$CR(4)_{Munic}$] largest fuelwood-producing municipalities in RN (Figure 4.b.) was 20.02%, indicating a low concentration. The highest CR(4)



Legend: Q1 Low Q2 Medium Q3 High Q4 Very High

		Q1	Q2	Q3	Q4
Micro.	1990	0 < Q1 ≤ 250	250 < Q2 ≤ 500	500 < Q3 ≤ 750	750 < Q4 ≤ 1,001
	2000	0 < Q1≤ 543	543 <Q2≤ 108	108 < Q3 ≤ 162	162 < Q4 ≤ 217
	2010	0 < Q1≤ 70	70 <Q2≤ 141	141 < Q3 ≤ 212	212 < Q4 ≤ 283
	2017	0 < Q1≤ 33	33 < Q2 ≤ 66	66 < Q3 ≤ 99	99 < Q4 ≤ 133
Munic.	1990	0 < Q1≤ 65	65 <Q2≤ 130	130 < Q3 ≤ 195	195< Q4 ≤ 260
	2000	0 <Q1≤ 21	21 < Q2 ≤ 42	42 < Q3 ≤ 64	64 < Q4 ≤ 85
	2010	0 < Q1≤ 18	18 < Q2 ≤ 37	37 < Q3 ≤ 56	56 < Q4 ≤ 75
	2017	0 <Q1≤ 11	11< Q2 ≤ 22	22< Q3 ≤ 33	33< Q4 ≤ 44

Figure 1 - Quartiles of fuelwood production derived from vegetation extraction in the microregions and municipalities of Rio Grande do Norte (RN) for 1990, 2000, 2010, and 2017, expressed in thousand cubic meters (x10^3 m^3).
Source: The Authors (2019).

$_{Munic}$ was 25.62% (2012) and the lowest was 16.03% (2001). The following municipalities contributed to the $CR(4)_{Munic}$: Marcelino, Apodi, Caraúbas, Baraúna and Canguaretama. The following municipalities contributed at least in one year to the $CR(4)_{Munic}$: Natal, Lagoa Nova, Mossoró, Alexandria, São Miguel, Governor Dix-Sept Rosado, Caicó, Açu, Currais and Parelhas. The mean concentration ratio of the

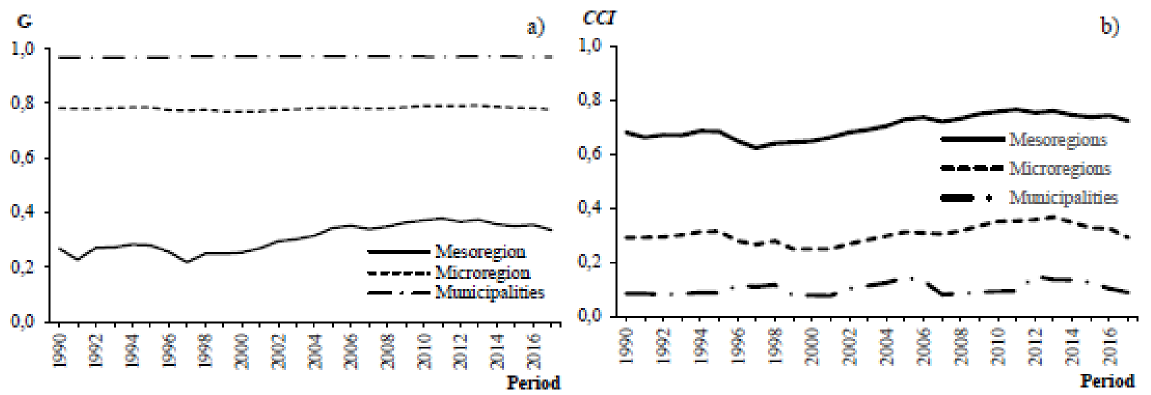


Figure 2 - The comprehensive concentration index (*CCI*) and Gini index (*G*)demonstrate the progress of fuelwood production at regional levels in Rio Grande do Norte (RN) from 1990 to 2017.
Source: The Authors (2019).

eight largest municipalities [$CR(8)_{Munic}$] was 31.22% and classified as moderately low concentration, with the highest concentration in 2005 (37.00%) and the lowest in 1999 (27.56%). The following municipalities contributed the most to the $CR(8)_{Munic}$: Alexandria, São Miguel Cerro Corá, Caraúbas, Marcelino Vieira, Baraúna, Apodi, Canguaretama, Governador Dix-sept Rosado, Lagoa Nova and

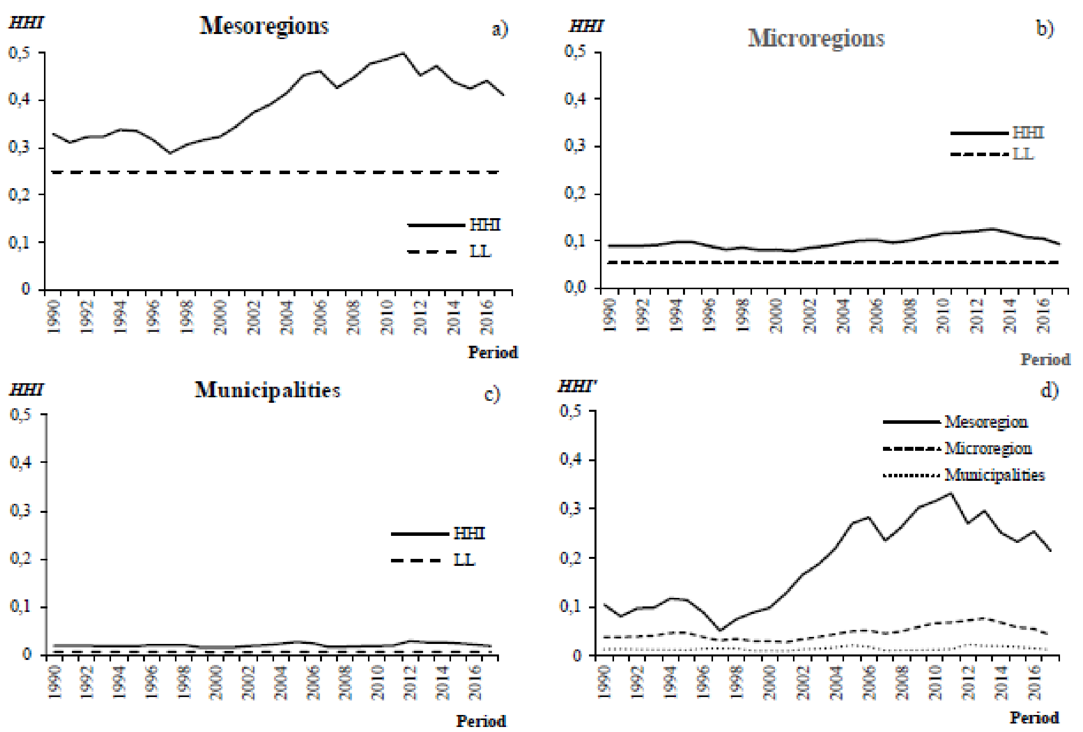


Figure 3 - The Herfindahl-Hirschman Index (*HHI*)demonstrates the progress offuelwood production at regional levels in Rio Grande do Norte (RN) from 1990 to 2017.
Source: The Authors (2019).

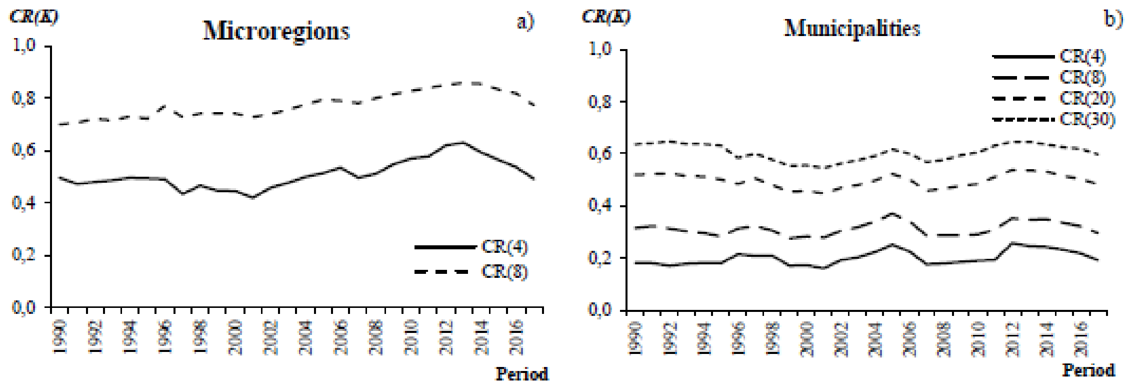


Figure 4 - The Concentration Ratio [*CR(k)*] demonstrates the progress offuelwood production at regional levels in Rio Grande do Norte (RN) from 1990 to 2017.
Source: The Authors (2019).

Parelhas. The municipalities that contributed at least once to the $CR(8)_{Munic}$: Mossoró, Encanto, Santana dos Matos, Caicó, Jardim do Seridó, Currais Novos, Natal, Tenente Ananias, Antônio Martins, Coronel João Pessoa, Bodó and Açu. The mean Concentration Ratio of the 20 largest municipalities [$CR(20)_{Munic}$] was 49%, with the highest concentration in 2012 (53.74%) and the lowest in 2001 (44.78%). The mean concentration ratio of the 30 largest municipalities [$CR(30)_{Munic}$] was 60.47%, with the highest $CR(30)_{Munic}$ in 1992 (64.72%) and the lowest in 2001 (54.50%). However, the $CR(20)_{Munic}$ and $CR(30)_{Munic}$ revealed that competition exists between the fuelwood-producing municipalities in RN.

CONCLUSION

Based on the analyses, fuelwood production in RN declined at an annual rate of -2.76%, from 5,280 x10^3 m^3 in 1990 to 777 x10^3 m^3 in 2017. Most municipalities in the state have low production of fuelwood derived from vegetation extraction. G inferred a very strong to absolute inequality for the municipalities and a weak to null inequality for the mesoregions. The CCI indicated an unconcentratedmarket in the municipalities and regional concentration in the mesoregions. The HHI corroborated this result by detecting a highly competitive market for the municipalities and microregions and a concentrated market for the mesoregions. The *CR*(*k*) of the four largest municipalities indicated a moderately low concentration. Therefore, fuelwood production in the state of RN presents an unconcentrated market structure.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

ACKNOWLEDGEMENTS

We thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for financial support.

AUTHORS' CONTRIBUTIONS

LMCJ: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft and Supervision. JVCB: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft. AMMN: Investigation, Writing - Original Draft. MSJ: Visualization, Writing- Reviewing. ANS: Methodology, Visualization. LACB: Writing- Reviewing and Editing.

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