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Articles

Analysis of the world concentration of pellet exports (2012-2018)

Análise da concentração mundial das exportações de pellets (2012-2018)

Helena Cristina Carvalho Soares[I]
Álvaro Nogueira de Souza[I]
Edvaldo Pereira Santos Júnior[II]
Anna Manuella Melo Nunes[III]
Luiz Moreira Coelho Junior[III]

[I]University of Brasília, Brasília, DF, Brazil
[II]Federal University of Pernambuco, Recife, PE, Brazil
[III]Federal University of Paraíba, João Pessoa, PB, Brazil

ABSTRACT

This work analyzed the world concentration of pellet exports between 2012 and 2018. Data on pellet exports from the Food and Agriculture Organization Of The United Nations – FAO were used as were the following indicators: Concentration Ratio [CR(k)], Hirschman-Herfindal Index (HHI), Theil Entropy Index (E), Gini inequality coefficient (G) and the Hall-Tideman Index (HTI). From the results, it was noted that there was an increase in the amount of world exports of wood pellets, with an increase from 9.71 $x10^6$ t, in 2012, to 23.67 $x10^6$ t, in 2018. There was dominance of the European continent over exports; at the country level, the main ones were: United States, Canada and Latvia. The indicators showed that pellet exports were, for the most part, concentrated and uneven. The continental and subcontinent levels showed the highest degree of concentration, however, as of 2016, there were signs of a possible deconcentration of this market. All methods used point to a process of deconcentration in pellet exports from 2016, this process can be intensified with technological expansion and incentive policies.

Keywords: Bioenergy; Densified biomass; Forest economy

RESUMO

Este trabalho analisou a concentração mundial das exportações de pellets entre 2012 e 2018. Utilizou-se os dados das exportações de pellets da Food and Agriculture Organization Of The United Nations – FAO e foram empregados os indicadores: Razão de Concentração[CR(k)], Índice de Hirschman-Herfindal (HHI), Índice de Entropia de Theil (E), Coeficiente de desigualdade de Gini (G) e o Índice de Hall-Tideman (HTI). Dos resultados notou-se que houve crescimento na quantidade de exportações mundial de pellets de madeira, com aumento de 9,71 $x10^6$ t, em 2012, para 23,67 $x10^6$ t, em 2018 . Observou-se domínio do continente europeu sobre as exportações; em nível de países, foram os principais: Estados Unidos, Canadá e Latvia. Os indicadores apontaram que as exportações de pellets estiveram, em sua maioria, concentradas e desiguais. Os níveis continental e de subcontinentes apresentaram o maior grau de concentração, contudo, a partir de 2016, houve indícios de uma possível desconcentração desse mercado. Todos os métodos utilizados apontam para um processo de desconcentração nas exportações de pellets a partir de 2016, esse processo pode ser intensificado com expansão tecnológica e de políticas de incentivo.

Palavras-chave: Bioenergia; Biomassa densificada; Economia florestal

1 INTRODUCTION

Fossil fuels emit greenhouse gases (GHG), causing irreversible climate change and compromising the environment, living beings and future generations. It is therefore necessary to meet the world's growing energy demand in line with sustainable development. To this end, renewable energy sources, including densified solid biofuels (pellets and briquettes), have become the focus of attention for researchers, governments and the energy market, especially since the Kyoto Protocol was ratified on March 15, 1999 (IPCC, 2014).

Investment and growth in global renewable energy play an important role in achieving sustainable development goals and combating climate change (Gu; Zhou, 2020). Clean energy sources are the fastest growing, accounting in 2019 for half of global supply and by 2040 they will be the largest source of energy in the world (Dudley, 2019). However, carbon emissions are still rising, which signals the need for comprehensive policy measures to achieve the goal of less carbon. To achieve the objectives of the Paris agreement, the renewable energy sector requires public and private investment of US$12 trillion by 2040 (IEA, 2019; REN21, 2019).

The use of pellets is important for reducing CO_2 (carbon dioxide) emissions, one of the main gases responsible for the greenhouse effect. The production of a unit of KWh of energy for residential heating from this resource (taking into account production, transportation and combustion) is six times less when compared to fossil fuel oil (Pinel, 2013). As well as being potentially sustainable sources, pellets must meet the interests of the consumer market. To this end, quality in chemical and physical properties is essential, for example, uniformity and structural strength facilitates transportation, storage and burning in combustion chambers, contributing to greater efficiency (Tavares; Tavares, 2015).

Because they are smaller than briquettes, pellets have a number of advantages, since they allow for better logistics, making them more attractive to the international market and justifying the low interest in selling briquettes, while foreign trade in pellets has increased significantly (Caraschi; Garcia, 2012). In addition, the evolution of pellet prices on the world stage between 2010 and 2015 has shown greater stability than liquid propane gas and fuel oil over the years (Association Pour les Energies Renouvelables, 2015; Pinel, 2013). The prices of forest pellets are generally more stable than those of fossil fuels, which contributes to greater long-term energy cost security and favors the diversity and sustainability of countries' energy matrix (Quenó, 2019).

The Food and Agriculture Organization of the United Nations (FAO) began recording the global pellet market in 2012. According to the organization, pellet exports worldwide rose from 1.6 billion to 3.7 billion dollars in 2018, with an annual growth rate of 15.0%. Based on the continents, more than 50% of this amount was concentrated in Europe. However, the largest exporter of wood pellets in 2018 was the United States, with more than 25% of the world's total exports.

The rapid growth of the pellet market has prompted research to better understand its market structure. The structure of the market can affect both its own efficiency and change incentives for innovation (Aghion; Bloom; Blundell; Griffith; Howitt, 2014). The study of industrial concentration helps to develop this knowledge, since high

concentration implies less competition between participants and, consequently, an increase in market power (Possas, 1999). The term concentration can be understood as the accumulation of economic attributes (income, wealth, production, among others) by a corresponding control unit (firm, individual, country, industrial establishments) (Braga; Mascolo, 1982).

Some studies have been published on concentration, including Le and Vo (2020) who analyzed the effect of concentration on performance in Vietnamese commercial banks during the period 2005-2012. The concentration of the forestry market can be found on the international stage: Heimann, Gonçalves, Dresch and Silva (2015) analyzed the concentration of the mouldings market imported by the United States between 2005 and 2009; Noce, Carvalho, Canto, Silva and Mendes (2007), for the international plywood market; Selvatti, Borges, Soares, Souza and Coelho Junior (2018) who evaluated the concentration in the global production of MDF; Coelho Junior, Burgos and Santos Júnior (2018) analyzed world pulp exports and Soares Souza, Santos Júnior, Nunes, Joaquim and Coelho Junior (2021) investigated the concentration of imports in the wood pellet sector on a global scale. At the regional level, several studies stand out for the Brazilian scenario, such as: Santos Júnior, Silva, Simioni, Rotela Junior, Menezes and Coelho Junior (2022) who analyzed the concentration of the Brazilian electricity supply from forest resources; Coelho Junior, Burgos and Santos Júnior (2018) for the concentration of firewood in Paraíba, Brazil, based on the gross production value and Coelho Junior (2016) for the regional concentration of the gross production value of jatropha in Paraná, Brazil. Although the literature presents various applications for this methodology, there are no studies of the market concentration of pellet exports on the world stage.

In view of the above, this article analyzed the global concentration of forest wood pellet exports between 2012 and 2018.

2 MATERIALS AND METHODS

2.1. Data

The data used to measure the concentration of pellet exports worldwide was obtained from the FAO for the years 2012 to 2018. The software used to process the data and carry out the methodology was Microsoft Excel. The analysis used the evolution of pellet exports from the continents between 2012 and 2018, from the ten largest exporters, based on 2018, from Brazil and the world. In order to estimate the gains and losses of global pellet sales, the Geometric Growth Rate (GGR) was used, expressed as an annual percentage (% p.a.), according to Equation (1), (Cuenca; Dompieri, 2016).

$$GGR = \left[\left(n\sqrt{\frac{V_n}{V_0}}\right) - 1\right] * 100 \quad (1)$$

Where: V_n = value of exports, in tons (t), of pellets in the final year; V_0 = value of exports (t) of pellets in the initial year; n = time variation (expressed in years).

2.2. Measures of concentration and inequality

The concentration indicators used in this study were: Concentration Ratio, Hirschman-Herfindal Index, Theil Entropy Index, Gini Coefficient and Hall-Tideman Index, described below:

The Concentration Ratio [CR(k)], Equation (2), considers the participation of the k regions (countries and subcontinents) that are the largest sellers of pellets on the international stage, in descending order.

$$CR(k) = \sum_{i=1}^{k} S_i \quad (2)$$

Where: CR(k) = Concentration Ratio of k exporters (countries and subcontinents) of pellets; Si = market share, the participant's exports in relation to the total exports, in percentage, of seller i (countries and subcontinents) in world pellet exports.

The concentration ratios of the four [CR(4)] and eight [CR(8)] largest exporters (countries and subcontinents) were calculated and ranked, as shown in Table 1. Also in this study, the twenty [CR(20)] and thirty [CR(30)] largest exporting countries and the two [CR(2)] for the subcontinents were measured.

Table 1 – Classification of the degree of concentration of the four and eight largest pellets exporting countries

Degree of Concentration	CR(4)	CR(8)
Very High	75% or more	90% or more
High	65% - 75%	85% - 90%
Moderately High	50% - 65%	70% - 85%
Moderately Low	35% - 50%	45% - 70%
Low	35% or less	45% or less

Source: Bain (1959)

The Herfindahl-Hirschman Index (HHI) measures industrial concentration using the sum of the squared share of pellet exports of all participants (countries, subcontinents and continents), using Equation (3).

$$HHI = \sum_{i=1}^{n} S_i^2 \quad (3)$$

Where: n = number of regions (countries, subcontinents and continents) selling pellets in the world; Si = market share, in percentage, of region i for the value of pellet sales.

The HHI shows the relative weights of the participants, because when it is squared, greater weight is given to those with greater participation (Coelho Junior; Santos Júnior; Nunes; Souza; Borges; Simioni, 2021). The index varies from 1/n (when all regions export the same amount) to 1 (when there is maximum concentration, monopoly). When the number of exporters varies over time, the lower limit (1/n) of the HHI also varies, making comparison difficult. To solve this limitation, Resende (1994) proposes the adjusted Herfindahl-Hirschman Index (HHI'), Equation (4), in which the HHI' limits are fixed between 0 and 1 and classified according to Table 2.

$$HHI' = \frac{1}{n-1}(nHHI - 1); \quad n > 1 \tag{4}$$

The Gini Coefficient (G) was initially developed to measure population income inequality (Gini, 1912). However, it can be used to measure the degree of inequality in pellet exports around the world, since the higher the concentration, the higher the inequality. The coefficient is calculated according to Equation (5).

$$G = 1 - \frac{\sum_{i=1}^{n}(S_{ij}+S_i)}{n} \tag{5}$$

Where: n = number of pellet exporting regions (countries, subcontinents and continents); S_{ij} = cumulative share of region i in the value of pellet sales in ascending order; S_i = market share, in percentage, of region i in the value of pellet sales. The index varies between 0 and 1, adopting the classification in Table 3.

Table 2 – Classification of the adjusted Herfindahl-Hirschman Index

Classification	Interval
Competitive market	*HHI'* < 0.10
Unconcentrated market	0.10 ≤ *HHI'* < 0.15
Moderate concentration	0.15 ≤ *HHI'* ≤ 0.25
High concentration	*HHI'* > 0.25

Source: Resende (1994)

Table 3 – Classification of the degree of inequality for the Gini coefficient

Classification	Interval
Zero to weak inequality	0.101 – 0.250
Weak to medium inequality	0.251 – 0.500
Medium to strong inequality	0.501 – 0.700
Strong to very strong inequality	0.701– 0.900
Very strong to absolute inequality	0.900 – 1.000

Source: Coelho Junior, Rezende, Ávila, Oliveira e Borges (2010)

The Theil Entropy Index (E), Equation (6), can be applied to the industrial economy to measure the concentration of any sector, in this case, the global sale of pellets.

$$E = -\sum_{i=1}^{n} S_i \ln(S_i) \quad (6)$$

Where: n = number of participants (countries, subcontinents and continents); S_i = market share, in percentage, of region i for the value of pellet sales; ln= Neperian logarithm.

Resende and Boff (2002) indicated the use of Theil's Entropy Index in industrial concentration analyses. The Entropy Index measures the inverse of concentration. The lower the value of the index, the more concentrated world pellet exports are.

Resende (1994) indicated the adjusted entropy index (E'), Equation (7), for intertemporal analysis. E' varies between 0, monopoly (maximum concentration), and 1, perfect competition (minimum concentration).

$$E' = -\frac{1}{ln\, n}\sum_{i=1}^{n} S_i\, ln(S_i) \quad (7)$$

The Hall-Tideman Index (HTI) is an inequality indicator that considers all pellet exporters involved in the activity, incorporating the ranking number into each one's share in Equation (8).

$$HTI = \frac{1}{2\sum_{i=1}^{n}(i.S_i)-1} \quad (8)$$

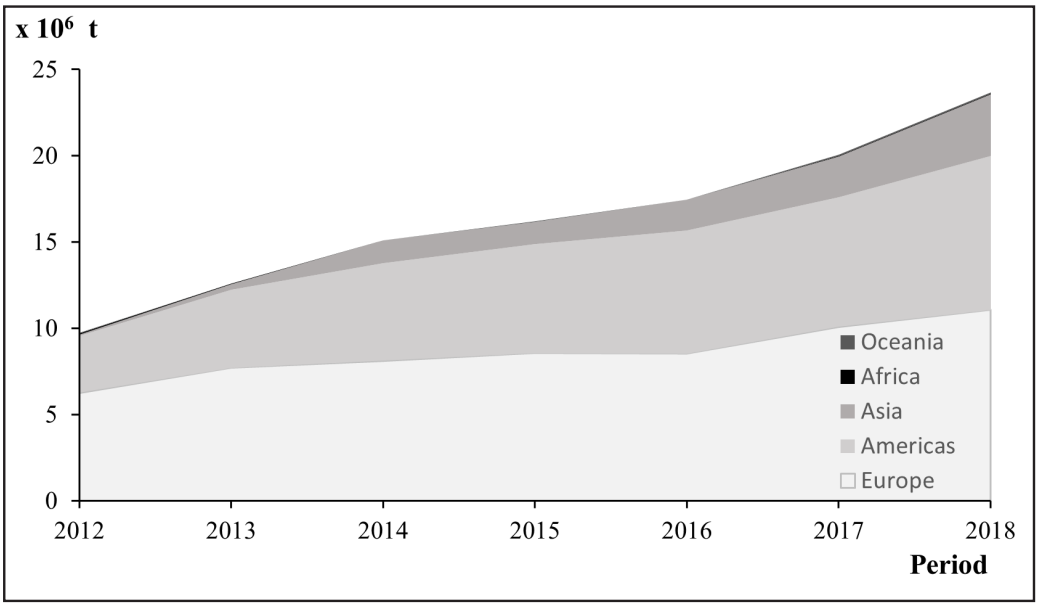
Where: n = number of participants, i = the participant's position in the ranking, S_i = market share, in percentage, of region i for the value of pellet sales. The HTI range varies between 1/n, a condition of perfect equality, and 1, a condition of monopoly or absolute inequality.

3 RESULTS AND DISCUSSIONS

Since 2012, all continents have participated in world pellet exports. Figure 1 shows the evolution of world pellet exports, in millions of tons ($x10^6$ t), distributed between the continents, from 2012 to 2018. In 2012, world exports amounted to 9.71

x10^6 t of wood pellets; of this amount, 64.39% came from Europe, 33.80% from America, 0.93% from Ásia, 0.85% from África and 0.02% from Oceania. This trade has grown and, in 2018, world exports of this biomass amounted to 23.67 x10^6 t, mobilizing 3.7 billion dollars (FAO, 2020). Europe's share of global wood pellet exports (46.76%) fell in 2018 compared to 2012. This was due to the sharp increase in this market in Asia, which accounted for 15.16% of total exports worldwide in 2018.

Figure 1 – Export of pellets (in 10^6 t) distributed across continents, between the years 2012 and 2018



Source: FAO (2020)

China's intense investments, including in the green economy, in the Belt and Road Initiative (BRI) countries, may justify Asia's advance in pellet exports. According to Liu and Hao (2018) there is a direct link between GDP (Gross Domestic Product) per capita and energy consumption, so these investments will result in a significant increase in electricity demand from BRI members in the near future to meet the basic electricity demand of the expected growth (IEA, 2017). These countries are important energy production bases in the world, with enormous potential for growth and development of renewable energy, as they have an abundance of renewable resources (Le; Vo, 2020).

In 2018, among the countries, the top ten pellet exporters were: the United States, Canada, Vietnam, Latvia, Russia, Estonia, Austria, Malaysia, Denmark and Germany. Vietnam had the highest geometric growth rate (GGR) (103.92% p.a.) and Germany the lowest (-5.10% p.a.). While world exports showed a growth rate of 16.01% p.a. (2012 - 2018), the top ten exporters showed an annual growth rate of 17.91%, p.a. higher than the rest of the world. Table 4 shows the evolution of annual exports (x103 to^{n}s) of the top ten pellet exporters in 2018, from Brazil and rest of the world, their respective GGR, ranking of the top ten and the number of exporting countries for the years between 2012 and 2018.

Most of the major exporters only alternated positions, but the United States and Canada remained at the top of the ranking for the entire period studied. The history of pellet production in the United States is notable; between 2003 and 2010 it increased its production capacity more than fourfold, reaching 4.9 million tons in 2010 (Nunes; Matias; Catalão 2016). Almost all of what was produced was consumed domestically (around 80%), but since 2009 large-scale pellet factories have been built, including those for export (Mandell; Lang, 2013; Sikkema; Steiner; Jungiger; Hiegl; Hansen; Faaij, 2011). According to the FAO (2020), from 2012 to 2018, wood pellet production in the USA grew from 1.8 to 6.0 million tons and in 2018, the country exported 80.57% of its production.

Other countries that showed sharp growth in this trade between 2012 and 2018 were: Brazil, with GGR = 478.70% p.a., followed by Greece (195.81% p.a.), Montenegro (157.31% p.a.), Thailand (142.4% p.a.), Albania (132.35% p.a.), Vietnam (103.92% p.a.). The GGR of these countries is much higher than that of the world (16.01% p.a.) or even that of the top ten exporters (17.91% p.a.). This may suggest a tendency for the scenario to change in a short space of time.

The wood pellet market in Brazil is more than two decades behind Europe and North America and, as a result, national pellet production and domestic consumption technologies are lagging behind (Garcia; Caraschi; Ventorim; Vieira, 2016). However, Brazil has comparative advantages that make it easier to compete in the international

market, which justifies the GGR analysis. The country jumped from 56th place to 20th in the ranking of top exporters from 2012 to 2018. Brazilian pellets made from pine wood shavings are of good quality and can obtain the European Premium ENplus certification, which is promising for the export of this biomass. Pellet production in Brazil is concentrated in the south of the country, especially in the states of Santa Catarina and Paraná. In 2015, the region had 13 factories, three with the ENplus quality seal and two in the certification phase (Garcia; Caraschi; Ventorim; Vieira, 2016; Quéno, 2015).

Table 4 – Evolution of annual exports (10^3 tons) of the ten largest pellet exporters in 2018, from Brazil and rest of the world, their respective GGR, ranking of the ten largest and the number of exporting countries for the years between 2012 and 2018

Countries	2012	2013	2014	2015	2016	2017	2018	GGR (%)
United States	1,898.13	2,882.52	4,005.06	4,669.00	4,709.00	5,203.98	6,017.00	21.20
Canada	1,369.00	1,640.23	1,637.39	1,627.78	2,373.11	2,171.50	2,651.44	11.65
Vietnam	34.21	743.63	879.03	974.71	1,353.61	1,620.73	2,460.00	103.92
Latvia	902.03	1,055.87	1,290.35	1,605.19	1,611.43	1,579.47	1,666.00	10.77
Russia	728.54	776.74	778.55	934.86	1,073.22	1,438.54	1,510.96	12.93
Estonia	430.43	482.8	723.12	883.39	945.85	1,250.60	1,111.95	17.14
Austria	476.28	456.61	485.27	690.33	609.53	671.24	780.89	8.59
Malaysia	37.06	165	149.50	245	469.72	526.99	703.29	63.32
Denmark	54.00	126.70	89.00	180.30	266.26	489.88	698.00	53.19
Germany	848.78	612.74	640.84	559.13	365.07	475.66	620.16	-5.10
Brazil	0.01	0.19	6.66	24.37	35.76	108.38	225.36	478.70
Rest of the world	2,933.54	3,631.18	4,417.37	3,786.55	3,648.75	4,518.33	5,224.09	10.10
World	9,711.99	12,574.21	15,102.13	16,180.60	17,461.29	20,055.30	23,669.14	16.01
1º	USA	USA	USA	USA	USA	USA	USA	-
2º	CAN	CAN	CAN	CAN	CAN	CAN	CAN	-
3º	LVA	LVA	LVA	LVA	LVA	LVA	VNM	-
4º	DEU	PRT	RUS	VNM	VNM	VNM	LVA	-
5º	RUS	RUS	VNM	RUS	RUS	RUS	RUS	-
6º	PRT	DEU	PRT	EST	EST	EST	EST	-
7º	AUT	EST	DEU	PRT	AUT	AUT	AUT	-
8º	EST	AUT	EST	DEU	PRT	MYS	MYS	-
9º	ROU	ROU	AUT	AUT	DEU	DEU	DNK	-
10º	LTU	BEL	NLD	ROU	LTU	PRT	DEU	-
n. of countries	59	64	68	64	62	61	60	-

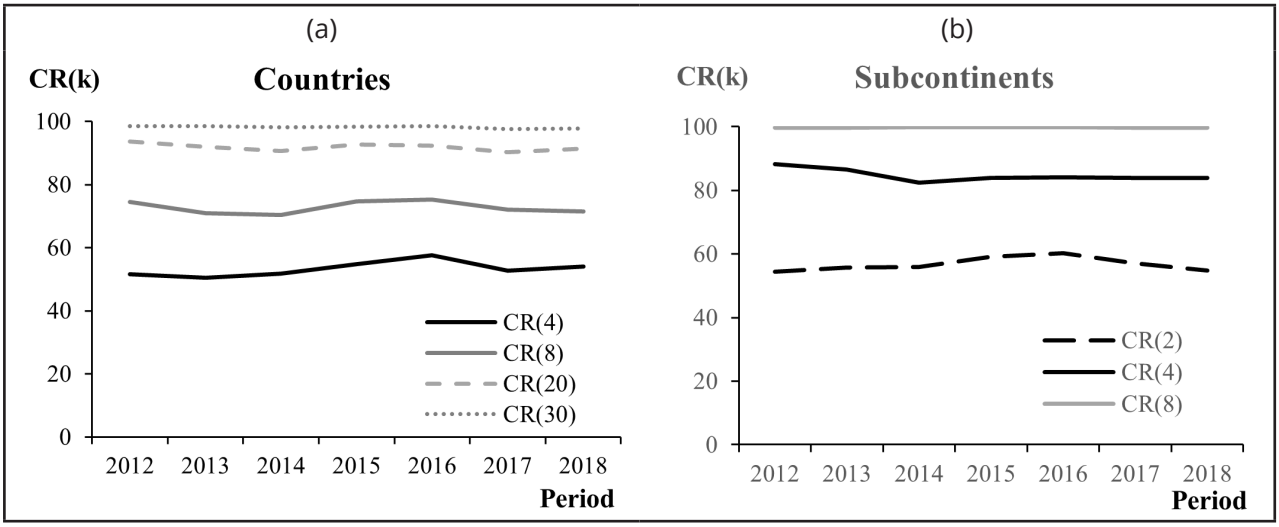
Source: FAO (2020)

In where: ISO codes: AUT = Austria; BEL = Belgium; CAN = Canada; DEU = Germany; DNK = Denmark; EST = Estonia; MYS = Malaysia; LTU = Lithuania; LVA = Latvia; PRT = Portugal; ROU = Romania; RUS = Russia; VNM = Vietnam; NLD = Netherlands; GGR = Geometric Growth Rates.

Currently, there is still a concentration of pellet exports in the world, with more than 90% of world exports still dominated by the twenty largest exporting countries, most of which belong to the European continent. It is therefore possible that there is a tendency for Europe to exert its market power on the international market.

Figure 2 shows the evolution of the Concentration Ratio [CR(k)] of world pellet exports from 2012 to 2018. Figure 2.a shows the CR(k) of the countries [CR(k)$_c$] e and Figure 2.b shows the CR(k) of the subcontinents [CR(k)$_s$]. Fluctuations were observed in all the CR(k), especially when considering the four [CR(4)$_c$] and eight [CR(8)$_p$] largest exporting countries. For the subcontinents, variation was noted for the two largest [CR(2)$_s$]. The $CR(4)_c$ had an average of 53.30% and was categorized as having a moderately high concentration (BAIN, 1959). The index rose from 51.67% (2012) to 54.05% (2018), with an average standard deviation of 2.38. The lowest concentration occurred in 2013, when the United States, Canada, Latvia and Russia accounted for 50.54% of world pellet exports. The highest concentration occurred in 2017, with 52.73% of exports made by the United States, Canada, Latvia and Vietnam.

Figure 2 – Evolution of the concentration ratio [CR (k)] of the world export of pellets, for (a) countries and (b) subcontinents, from 2012 to 2018



Source: Authors (2023)

CR(8)$_c$ showed similar results to CR(4)$_c$, with an average of 72.75%, classifying the market as having a moderately high concentration. The year with the highest

concentration was 2015 (74.62%) and the year with the lowest was 2013 (70.90%). The following participated in the $CR(8)_c$: Austria, Canada, Estonia, Germany, Malaysia, Portugal, Russia, the United States and Vietnam. The average $CR(20)_c$ was 91,86% and the $CR(30)_c$ 98.19%. The number of participants decreased from 59 in 2012 to 60 in 2018. Costa, Mahanzule, Aguiar and Silva (2018) studied the concentration of Brazilian chemical cellulose exports between 1990 and 2010 and also identified high concentration for CR(4) and CR(8).

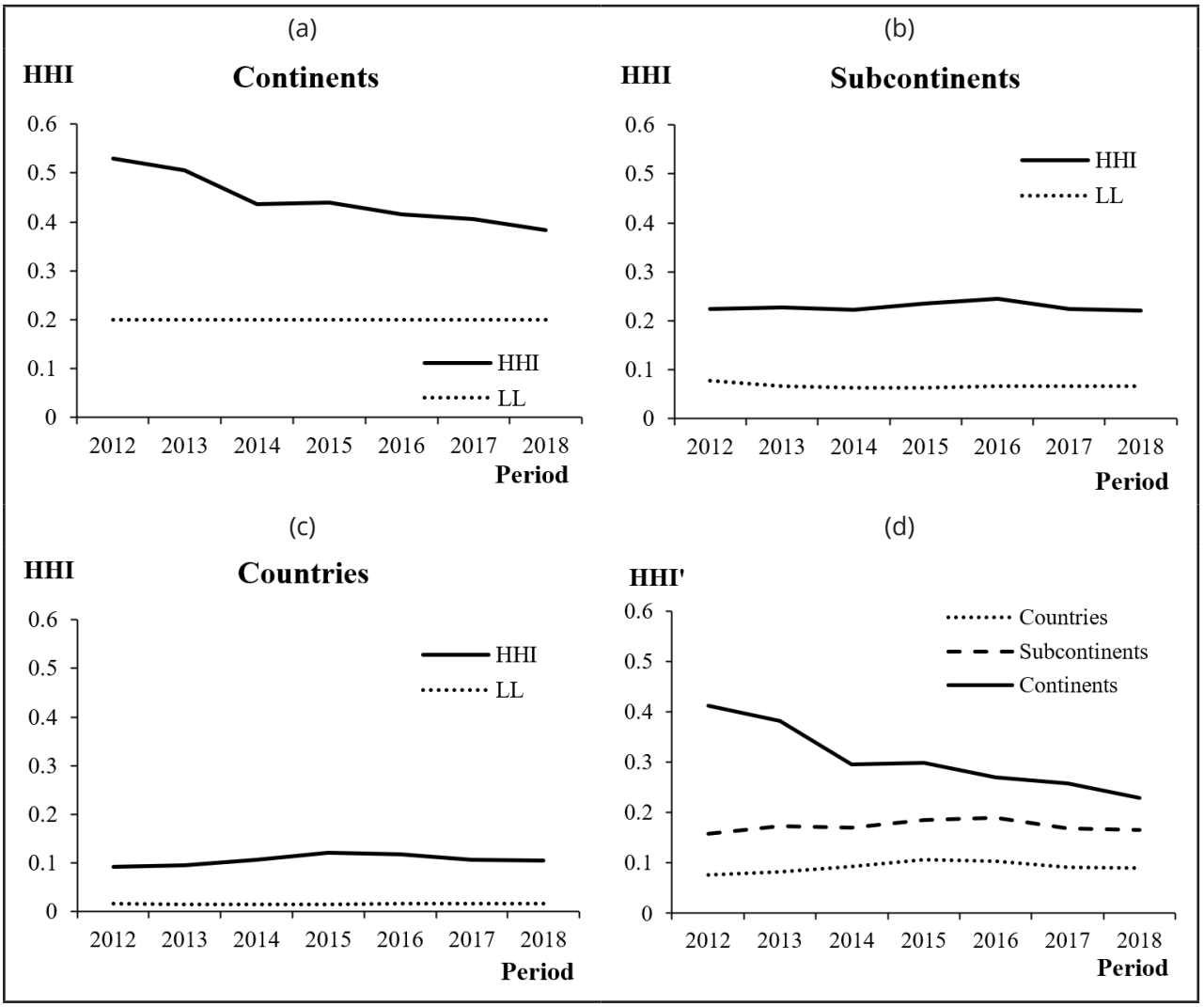
The number of pellet-exporting subcontinents rose from 13 to 15 members between 2012 and 2018. In 2012, $CR(2)_s$ were 54.32%, rising to 54.81% in 2018. The average index was 56.74%, with North America and Northern Europe dominating. For $CR(4)_s$, the index rose from 88.28% (2012) to 83.99% (2018), with an average of 84.72%, resulting in a moderately high concentration market. The $CR(4)_s$ included the following regions: North America, Northern Europe, Eastern Europe and Southeast Asia. The $CR(8)_s$ howed very high market concentration throughout the period analyzed. There was little variation in the index, from 99.75% (2012) to 99.78% (2018).

Figure 3 shows the evolution of the Herfindahl-Hirschman Index (HHI) for world pellet exports from 2012 to 2018, Figure 3.a shows the HHI for Continents (HHI_{cont}), igure 3.b shows the HHI for Subcontinents (HHI_s), Figure 3.c shows the HHI for countries (HHI_c) and Figure 3.d shows the adjusted Herfindahl-Hirschman Index (HHI') for pellet exports from countries, subcontinents and continents. It was observed that, in general, over the period studied, the HHI of all levels was close to their respective Lower Limits (LL), indicating a deconcentration in the sector. This confirms the propensity to reduce concentration indicated by the concentration ratio [CR(k)].

Since the LI depends on the number of participants, over the period analyzed, the LI was constant for the continents and varied little for the subcontinents and countries. Thus, the higher the HHI, the greater the difference in LI and the greater the concentration. For the continental level, the HHI_c decreased from 0.5291 (2012) to 0.3832 (2018), these years also representing, respectively, the highest and lowest

concentration of the export market (Rezende, 1994). For the subcontinents, the greatest difference between the HHIs and the LIs was 0.1777 (2016) and the least in 2012 (0.146).

Figure 3 – Evolution of the Herfindahl-Hirschman Index (HHI) for the level of (a) continent, (b) subcontinents and (c) countries, and (d) adjusted HHI, for world pellet exports, from 2012 to 2018



Source: Authors (2023)

The increase in the index in 2016 was also observed for the $CR(2)_s$, which showed a maximum value for the series, highlighting the strong participation of North America and Northern Europe. For the countries, the HHI rose from 0.0918 (2012) to 0.1054 (2018). The growth in the HHI can be explained by the increase in exports from the

United States and Canada during this period. The average difference between the HHI_c and the LI_c was 0.0902. In 2015, there was the greatest difference between the indices (0.1048) and in 2012, the least (0.075). From 2016 to 2018, the difference between the HHI_p and LI_c fell, indicating deconcentration. The departure of Armenia and Georgia from the export scene justifies a drop in concentration, given that these countries had very low exports (approximately 1 tonne of pellets), which resulted in a greater discrepancy between the participants. The HHI'_{cont} of pellet exports from the continents decreased from 0.4113 (2012) to 0.2290 (2018), with an average of 0.6063, which characterized a high concentration market. It was only in 2018 that HHI'_{cont} changed its classification to moderate concentration. HHI'_s, in turn, had a maximum value of 0.1904 (2016) and a minimum of 0.1585 (2012), behaving like moderate concentration throughout the time period studied.

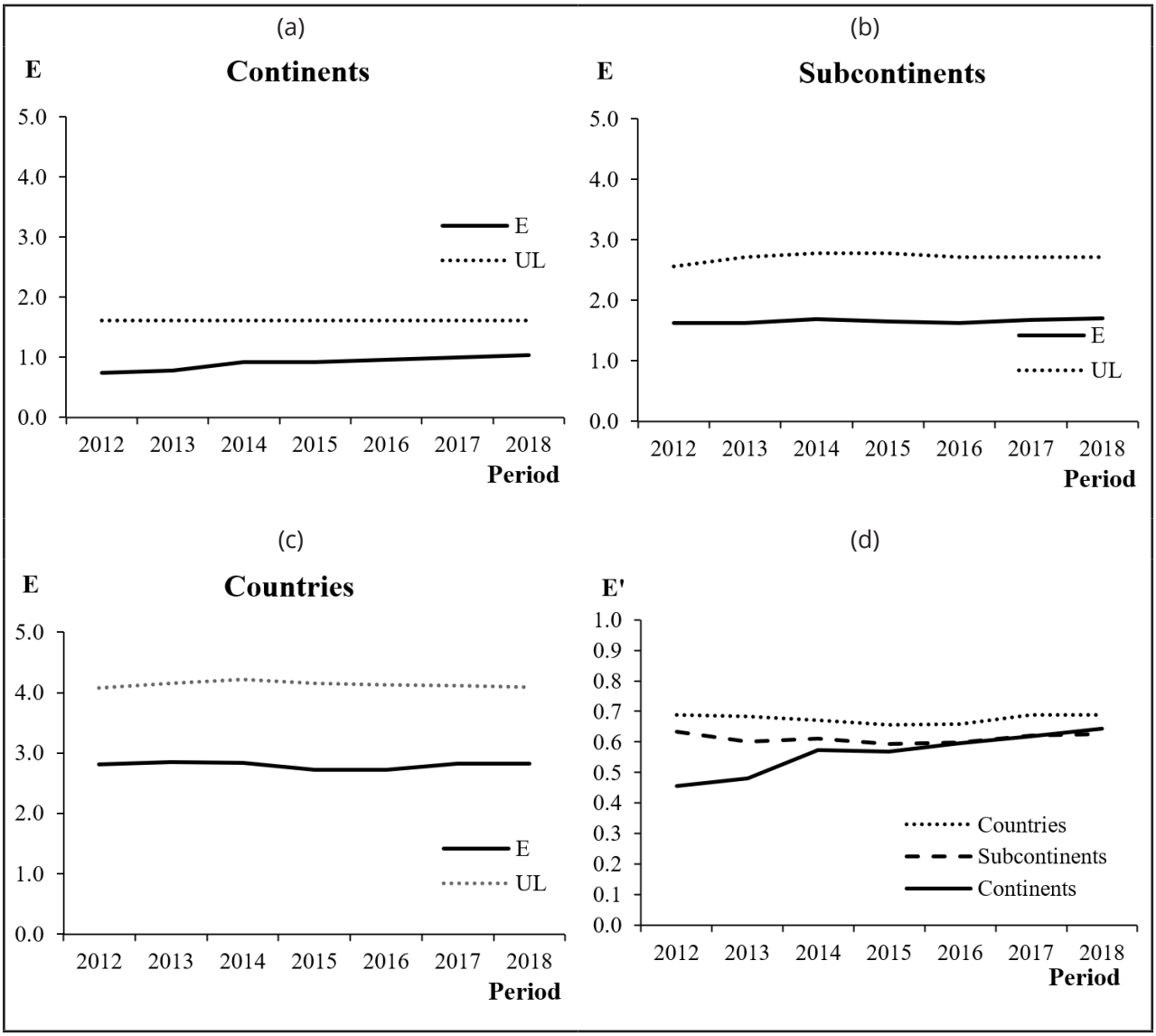
The countries' HHI' (HHI'_c) in 2012 was 0.076 (minimum value); in 2016, it was 0.1904 (maximum value) and in 2018, the indicator fell again, with HHI'_c = 0.090. HHI' values below 0.1 characterized an atomized or competitive market, as classified by Resende (1994). It is important to note that the index incorporates the number of countries that exported in each year, so the withdrawal of some participants with few exports results in increased competition between nations. Finally, the HHI'_c from 2012 to 2014 and from 2017 to 2018 was classified as a competitive market. For 2015 and 2016, the sector was not concentrated (range between 0.10 and 0.15). Costa, Mahanzule, Aguiar and Silva (2018) also used the Herfindahl-Hirschman Index and classified the concentration of the Brazilian chemical pulp market as moderately concentrated.

Figure 4 shows the evolution of the Theil Entropy Index (E) for world pellet exports from 2012 to 2018, Figure 4.a the E of the Continents (E_{cont}), Figure 4.b the E of the Subcontinents (E_s), Figure 4.c the E of the countries (E_c) and Figure 4.d shows the adjusted Theil Entropy Index (E') of the countries, subcontinents and continents.

In the analysis for continents, the lowest E_{cont} value found was 0.7355 in 2012 and the highest E_{cont} was 1.0362 in 2018. The average difference between the E_{cont} and its LS was 0.7040, with 2012 being the year of highest concentration. The fall in concentration at continental level demonstrated the expansion of the sector beyond the European continent, mainly to America. For the subcontinents, the minimum E_s

was 1.618 in 2016 and the highest E_s (1.6957) in 2018. The average difference between E_s and LS_s was 1.0516, showing concentration above the continental level, meaning that there are a few subcontinents that dominate the export scene globally. Among the countries, the highest E_c (2.8446) was recorded in 2013, and the lowest (2.7210) in 2016. The difference between E_c and LS_c had an average of 1.3385, indicating that the country level was the most concentrated. However, the three groups studied behaved similarly from 2015 onwards, with a decline in concentration.

Figure 4 – Evolution of Theil Entropy Index (E) for the level of (a) continent, (b) subcontinents, and (c) countries, and (d) E adjusted, for the world export of pellets, from 2012 to 2018



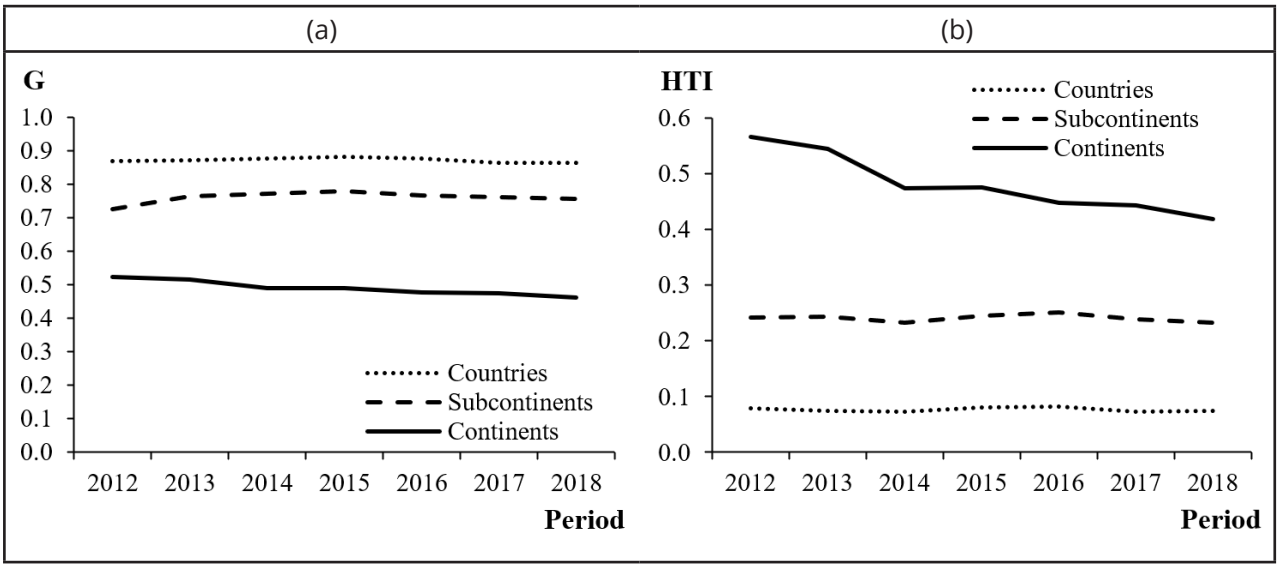
Source: Authors (2023)

The adjusted Theil Entropy (E'), Figure 4.d, indicates that the closer the export is to zero, the more concentrated it is. The average E'_{cont} was 0.5625, with the lowest concentration recorded in 2018 (E'_{cont} = 0.6438), the year with the highest concentration was 2012 (E'_{cont} = 0.6438), with the European continent dominating 64.39% of exports, in the following years, the increase in America caused a decrease in concentration. For subcontinents and countries, the lowest concentration was in 2012 (E'_s = 0.6334 and E'_c = 0.6889), while the highest concentration was in 2015 (E'_s = 0.5930 and E'_c = 0.6552). The average values (average E'_s = 0.6116 and average E'_c = 0.6763) indicated a market with concentration trends. The main observation from the adjusted index confirmed the results of Theil's Entropy and HHI', which indicated a decline in concentration for all groups (continent, subcontinent and countries).

The inequality of world pellet exports is shown in Figure 5.a according to the Gini Coefficient for the continents, subcontinents and countries between 2012 and 2018. Although there have been some variations in the performance of the inequality curves in the three groups, overall inequality has tended to decrease, especially since 2015. The highest coefficient values were for countries, followed by subcontinents and continents. Figure 5.b shows the behavior of concentration according to the Hall and Tideman Index (HTI). In all cases, a decrease in the index values can be seen from 2016 onwards, possibly revealing a downward trend in the concentration of world pellet exports for all the groups studied.

The average G_{cont} was (0.4902) which represented weak to medium inequality from 2012 to 2018 among the pellet exporting continents, ranging from 0.5234 in 2012 to 0.4612 in 2018, showing a drop in inequality. The average G_s (0.7606) was classified as strong to very strong, rising from 0.7260 (2012) to 0.7572 (2018) for the subcontinents. In turn, the G_c was 0.8683 (2012) to 0.8639 (2018), with an average of 0.8718 and a classification of strong to very strong inequality between countries. The increase in the number of exporting countries between 2012 and 2014 did not guarantee a reduction in inequality, as many countries were not yet highly competitive in pellet exports.

Figure 5 – (a) Gini coefficient (G) and (b) Hall and Tideman index (HTI), for countries, subcontinents and continents that export pellets, from 2012 to 2018



Source: Authors (2023)

Coelho Junior, Rezende, Ávila and Oliveira (2013) evaluated the forest products market using the Gini Coefficient and concluded that inequality was strong and absolute between 1961 and 2008. The authors pointed out that a small number of competitors concentrate increasingly larger fractions of exports, even with the increase in the number of countries exporting forest products. However, Costa, Mahanzule, Aguiar and Silva (2018) found that there was a reduction in inequality in the Brazilian chemical pulp market as the number of purchasing countries increased.

For the HTI, the level with the highest concentration was continents, with an average of 0.4816. Figure 5.b shows that exports, although concentrated, are tending to deconcentrate on a continental scale. The highest continental HTI value was 0.5663 in 2012 and the lowest was 0.4187 in 2018, which demonstrates the trend of increasing competition. For the subcontinents, the average HTI was 0.2409, with little variation over time. The most competitive market among the countries was the average HTI of 0.0770, indicating a deconcentrated market.

Waste from the Brazilian pine-based wood industry has proven to be a strong potential for pellet production. When properly used, this waste could represent 1.6

million tons of premium quality ENplus pellets (Quéno, 2015). Italy is the country's main consumer of forest wood pellets. In 2016, Italy bought almost all of Brazil's pellet production (SNIF, 2019).

In addition, Brazil can develop large-scale production techniques using eucalyptus as a raw material, since the country is a major producer (Quéno, 2019). The pelletization of eucalyptus wood is more complex when compared to conifers, as it requires more processing steps. However, torrefaction of eucalyptus raw material can be a good alternative to minimize this greater degree of difficulty, since torrefaction reduces the energy costs of producing pellets with greater added value, making them more competitive in the international solid biofuels market (Wild; Deutmeyer; Bradley; Hektor; Hess; Nikolaisen; Stelte; Tumuluru; Lamers; Prosukurina; Vakkilainen; Heinimö, 2016).

4 CONCLUSIONS

It can be concluded that during the study period there was growth in the quantity of wood pellet exports worldwide, with an increase from 9.71 $x10^6$ t (2012) to 23.67 $x10^6$ t (2018). Europe dominated exports; the main exporting countries were the United States, Canada and Latvia.

All concentration measurement methods classify global pellet exports as moderately high and not concentrated, indicating that the sector is expanding and multiple countries have a significant export market presence. At the continental level, Europe and America dominate global shares. The Gini Coefficient, a measure of inequality, assessed these exports as having strong to very strong inequality. Thus, the timid increase in the number of exporting countries was not enough to reduce inequality.

All the methods used point to a process of deconcentration in pellet exports from 2016 onwards. This movement indicates that pellet exports are expanding and that there is technological diffusion, making the fuel more accessible. Furthermore,

based on the results observed, it is expected that concentration will decrease in the coming years, an important factor for market consolidation. Tax and government incentives could help expand the use of pellets.

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Authorship Contribution

1 Helena Cristina Carvalho Soares

Master's degree

https://orcid.org/0000-0002-5479-0226 • helenacclodi@gmail.com

Contribution: Formal analysis; Writing – original draft; Writing – review & editing

2 Álvaro Nogueira de Souza

PhD.

https://orcid.org/0000-0002-6869-2715 • ansouza@unb.br

Contribution: Conceptualization; Project administration; Supervision; Writing – review & editing

3 Edvaldo Pereira Santos Júnior

Master's degree

https://orcid.org/0000-0003-1316-2247 • Edvaldo.junior@ufpe.br

Contribution: Methodology; Validation; Writing – review & editing

4 Anna Manuella Melo Nunes

Master's degree

https://orcid.org/0000-0002-2762-9330 • annamanuellam@gmail.com

Contribution: Investigation; Validation; Writing – review & editing

5 Luiz Moreira Coelho Junior

PhD.

https://orcid.org/0000-0001-5528-7799 • luiz@cear.ufpb.br

Contribution: Conceptualization; Project administration; Supervision; Writing – review & editing

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