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Large agri-food corporations in the global staple and cash crops markets: a quantitative analysis of rice and coffee through the virtual water perspective

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Abstract

The paper investigates the influence of major food corporations on global rice and coffee markets from 2013 to 2022, with a focus on market presence and water usage. It uses detailed data from the Euromonitor Passport and the CWASI datasets to analyze environmental impacts and virtual water (VW) flows at the company level, addressing gaps in the existing literature. Key findings show that although rice sales are larger than those of coffee in quantity, coffee embeds a higher total water use due to its greater unit water footprint (WF). The rice market is less internationalized and concentrated compared to the coffee market, where a few companies hold significant market shares across multiple countries. In 2022, the top 12 rice-selling companies control 16% of the global rice WF, exceeding the combined WF of the top three rice-importing nations. Similarly, the top 15 coffee-selling companies command 55% of the global roasted coffee WF, with significant disparities in VW quantities compared to major importing nations. The coffee market exhibits a higher number of companies with larger shares of WF than volumes, with this disparity increasing over time. Furthermore, more countries exhibit high and moderate concentration indices for coffee sales compared to rice. These findings highlight the considerable concentration of water resources among large companies, particularly in the coffee sector. The paper emphasizes the importance of considering the environmental implications of corporate activities in food supply chains, providing valuable insights for sustainability efforts in the agri-food industry.

1. Introduction

In recent decades, major agri-food enterprises have shifted their focus away from direct food production globally (Rama 2017). However, they still exert indirect control through contract farming with small-scale producers[4] (Bellemare *et al* 2022). These giants also play a direct role in food processing and trade, maintaining influence in the global food system (Oxfam 2013, Flach *et al* 2016, Chemnitz *et al* 2017, Rama 2017, Folke *et al* 2020, Scoppola 2021, UNCTAD 2023). Given that the food sector accounts for a substantial majority of water consumption, these companies are crucial in managing water resource and

[4] In contract farming, a large food enterprise and a grower make an agreement regarding the production of a specific agricultural commodity. The enterprise often provides agricultural inputs to the farmers as a loan. Contract farming may help reduce market uncertainties for farmers related to technology adoption and meeting market demand. It also helps large enterprises mitigate risks associated with long vertical integration processes (Bellemare *et al* 2022). However, large corporations may push small producers out of the market and limit their access to retailers. They often use lobbying with local governments and contract farming to expand their operations in new profitable markets. Additionally, the share of the end-price of products for small farmers seems to have declined in recent decades (Oxfam 2013, Chemnitz *et al* 2017).

virtual water (VW) associated with food production, processing, and distribution[5] (Sojamo *et al* 2012, Oxfam 2013, D'Odorico *et al* 2018, Folke *et al* 2019, Folke *et al* 2020). Their role in international food systems is significant in several ways, including direct food supply, vertical integration strategies along the value chain (from providing seeds and fertilizers for farmers to the management of manufacturing processes), lobbying by national trade organizations, and influencing global trade infrastructures, as well as finance and hedging solutions (Sojamo *et al* 2012, Scoppola 2021, Bellemare *et al* 2022). Sojamo *et al* (2012) highlight that the four largest agribusiness corporations (Archer Daniels Midland, Bunge, Cargill, and Louis Dreyfus—the so-called ABCD group) control from 70% to 90% of the international trade of staple food. Since staple crops contribute the most in percentage terms to total international VW flows, large agri-food enterprises can be considered major actors of global VW flows (Sojamo *et al* 2012).

Some scholars argue that VW analysis is a useful tool to inform policy or water rights systems, as it allows a comparison between actual water uses and available hydrological resources in a given area. It provides metrics on water consumption that is crop- and time-specific, differentiating by source (rain or irrigation; surface or groundwater) and providing information on the economic productivity of water (i.e. Euro/m^3). Moreover, analysis of the VW trade network provides information on water use efficiency in food-related commercial relations among countries (Al-Weshah 2000, Aldaya and Llamas 2008, Aldaya *et al* 2010).

Conversely, others scholars claim that policy makers should consider dynamics related to labor market, wider environmental impact, food security and livelihood, beyond VW information, for designing optimal food and water policies, and argue that the importance of water footprint (WF) analysis for policy purposes is overstated (Wichelns 2010).

Considering the role of large enterprises in food and water dynamics could help to address some of these concerns. Due to their significant involvement in national and international food value chains, from production to retail management, these enterprises could be specific targets for water governance policies. This could help to move beyond generic water-related recommendations for regions or states.

Additionally, these enterprises themselves could engage in sustainable practices, becoming actors of positive change for sustainability (Oxfam 2013, Rudebeck 2019, De Petrillo *et al* 2023). Choices pertaining the cultivation of staple *versus* cash crops by large enterprises have a significant impact on land, food, and water security worldwide (Barbier 1989, Oxfam 2013, Piyapromdee *et al* 2014, Chemnitz *et al* 2017). Moreover, similarly to the corporate role in reducing GHG emissions or preserving biodiversity and forests (Oxfam 2013, Folke *et al* 2019, De Petrillo *et al* 2023), large enterprises strongly influence also the economic water productivity of crops (Aldaya *et al* 2010).

The motivation for this research stems from two gaps in the literature: the need for more focus on environmental impacts in agri-food value chains (World Bank 2020, Bellemare *et al* 2022, Ponte 2022), and the relatively unexplored study of VW fluxes at the company level (Dalin *et al* 2012, D'Odorico *et al* 2018, Vallino *et al* 2021), despite some pivotal exceptions (De Petrillo *et al* 2023). Although large corporations are increasingly engaging in sustainability initiatives, and although their role is investigated in the food system literature (Scoppola 2021), they are less considered in institutional analyses of water governance and stewardship (Sojamo *et al* 2012, Folke *et al* 2019, 2020, De Petrillo *et al* 2023). Analyzing VW at the company level allows us to investigate the concentration of water use in the hands of large enterprises and their influence on resource allocation, making them crucial targets for water sustainability policies in the agri-food sector.

This paper undertakes an examination of the role played by large enterprises in the food sector, focusing on rice and coffee markets from 2013 to 2022 as case studies. We provide a quantitative analysis of the sale volumes of rice and coffee across all large companies participating in these markets. Additionally, we estimate the VW associated with the rice and coffee that these companies sell in all countries worldwide. We focus on one product belonging to the staple crops group (rice) and one to the cash crop group (coffee) to encompass the diverse market dynamics of foods with varying roles in human nutrition and agricultural value chains (Tosh 1980, Barbier 1989, Achterbosch *et al* 2014, Piyapromdee *et al* 2014, Elsby 2020, Falsetti *et al* 2020, El Mamoun *et al* 2020).

The novelty of the paper lies mainly in two dimensions: first, we observe the dynamics of large companies in the agri-food sector by exploiting granular data on firm sales of single products in numerous countries over time (Euromonitor International 2023), going beyond the simple information on the

[5] The water footprint is an indicator of water use that provides information on both direct and indirect water use of a consumer or producer (Aldaya *et al* 2010). The virtual water (VW) concept is closely related and it refers to the amount of water consumed for the production of a commodity (Allan 1998, Hoekstra and Mekonnen 2012). Virtual water trade is composed by the volume of water associated to the production of internationally traded goods (Hoekstra and Chapagain 2011). The trade of agricultural goods accounts for approximately 90% of the total VW displaced for human consumption (D'Odorico *et al* 2019). The VW embedded in traded food globally is about 25% of the total amount of water utilized for agriculture, and it has doubled from 1986 to 2007 (*ibid.*). The quantity of food exchanged on international markets from the 1990s to 2015 has increased almost three times faster than food production (Traverso and Schiavo 2020).

total company revenues provided by other databases. Secondly, we estimate the VW associated to those sales (Tamea *et al* 2021), to provide insights into environmental impacts along international food value chains beyond monetary and volume-related analyses.

2. Data and methods

To assess the role of companies in the rice and coffee markets, this study utilizes two datasets. Firstly, the Euromonitor Passport dataset (2023 release), provides financial information regarding rice and coffee sales by each company with a market share above 0.1% in each of 76 and 99 countries, respectively, spanning the 2013–2022 period[6]. The sample includes 350 companies in the rice market and 419 companies in the coffee market.

Secondly, the CWASI dataset estimates the unit water footprint of supply (uWFs) for the items 'rice milled' (UWF29) and 'coffee roasted' (UWF657) for every country[7]. The main advantage of the CWASI dataset lies in the time-variant information on the uWF of several primary and processed food items in different countries (Tamea *et al* 2021). With these datasets, we calculate the volume of rice and coffee sold by each company globally and within individual countries, as well as the volumes of WF associated with the sales of these two items by each company in every country.

In order to calculate the volume of rice sold by each company, we use the following two-step process. First, we determine the average price of rice in country i in year t, $price(i,t)$, using:

$$price\,(i,t) = value\,(i,t)\,/volume\,(i,t) \quad (1)$$

where $value_{it}$ is the total retail value of the rice sold in country i in year t, and $volume_{it}$ is the total quantity (expressed in tonnes) of rice sold in country i in year t.

Second, we calculate the quantity of rice sold by each company c in country i in year t, $volume\,(c,i,t)$ as:

$$volume\,(c,i,t) = value\,(c,i,t)\,/price\,(i,t) \quad (2)$$

where $value\,(c,i,t)$ is the retail value of rice sold by each company c in country i in year t.

Data on the quantity of coffee sold by each company in a country is directly provided by Euromonitor. Finally, for both rice and coffee, we calculate the volume each company c sold in year t in all N countries ($N = 76$ or $N = 99$ for rice and coffe, respectively):

$$volume\,(c,t) = \sum_{i=1}^{N} volume\,(c,i,t). \quad (3)$$

Additionally, we estimate the amount of virtual water associated with each company at the sale stage for each of the two products. We evaluate the company uWF, which is an average of the uWFs of the countries where the companies operate, weighted by the volumes they sell in those countries. This variable is a proxy for the amount of water associated with the sales of rice and coffee by each company, considering both production and processing, and both domestic production and imports, according to the methodology of Tamea *et al* (2021). To calculate this variable, we first calculate the $uWF\,(c,t)$ of a company as a weighted average mean:

$$uWF\,(c,t) = \sum_{i=1}^{N} uWFs\,(i,t) * Volume\,(c,i,t)\,/\sum_{i=1}^{N} Volume\,(c,i,t) \quad (4)$$

[6] Our sample encompasses large companies in the rice market (for example the Brazilian Camilo Alimentos, the Chinese COFCO, Wilmar from Singapore) and in the coffee market (for example, Nestlé, Lavazza, Tchibo, and the Indonesian Kapal Api Group). Other relevant datasets on global corporations are 'ORBIS' and 'fDi Markets'. The first provides information on total revenues, employees, and assets of millions of companies worldwide. The second includes data on greenfield FDI projects globally since 2003, with information on the value chain node in which the project is placed. Moreover, Thomson Reuters' 'Securities Data Company M&A (SDC)' and 'Zephyr' are the reference datasets on mergers and acquisitions (M&A). However, all these datasets do not provide disaggregated information on the revenues associated with single food items. To our knowledge, this information is present only in the Euromonitor Passport dataset. Detail at the food item level is necessary for the calculation of the water footprint associated with it, that is item-, place- and time-specific (Tamea *et al* 2021). Euromonitor does not provide information on the place of production, but only on the place of sale, which represents a limitation of this research. In order to elicit as much information as possible from the available data, we use the unit water footprint (uWF) of supply, according to established methodologies, as explained in footnote 4. Other datasets on water footprint include 'WaterStat' (Mekonnen and Hoekstra 2010), presenting the uWF of several food items using average values over the 1996–2005 period; datasets referring to irrigation water and water scarcity within the life cycle assessment framework (Pfister *et al* 2011, 2016); and the 'EORA' database, that contains assumptions on economic growth in the production sectors (Lenzen *et al* 2013). Crop production and trade data are retrieved by the CWASI project from FAOSTAT and UN-COMTRADE.

[7] The supply of a food item within a country results from both local production and imports, and imports may derive from producing or non-producing countries. The latter case implies a re-export of goods. Therefore, the unit water footprint of supply (uWFs) of an item is proportionally constituted of local production and of trade, including information on the relative contribution of every country from which the goods originated, considering re-exports and processing of goods, when necessary. The CWASI dataset includes water footprint information associated with food items until 2016. However, observing the relatively constant uWF trends from 2010 onwards, with respect to the steady declining trends between 1960 and 2010, we can reasonably assume that the uWFs for rice and coffee remain similar from 2016 to 2022 (Tamea *et al* 2021). Regarding food companies, we use the latest version of the Euromonitor Passport database (2023).

where *uWFs* (i,t) is the unit WF of supply of country i where the company sells its product (coffee or rice) in year t.

Second, we calculate the WF associated with the quantity of rice or coffee each company c sells in country i in time t, *WF* (c,i,t):

$$WF\,(c,i,t) = volume\,(c,i,t) * uWF\,(c,t) \quad (5)$$

where *volume* (c,i,t) is the quantity of rice or coffee sold by company c in a given country i in year t.

Finally, we also calculate the global WF associated with the food item (rice or coffee) that each company c sold in year t:

$$WF(c,t) = \sum_{i=1}^{N} WF(c,\,i,\,t). \quad (6)$$

3. Results

3.1. Global features

The worldwide volume of rice sales has shown a consistent increase from 2013 to 2022, with a period of stagnation between 2019 and 2020. On the other hand, coffee sales steadily rose from 2013 to 2021, but in 2022 the coffee market deviated from this trend by experiencing a decrease (in per capita terms, the decrease started in 2021) (figure 1)[8].

Table 1 shows that the average uWFs coffee is higher compared to that of rice, indicating the varying water resources needed for their production (Falsetti *et al* 2020). Despite rice's lower uWF, the total virtual water (VW) associated with rice in the hands of private companies globally exceeds that of coffee.

Table 2 provides an overview of the rice and coffee markets. Our sample includes 78 countries with 350 companies in the rice market and 99 countries with 419 companies in the coffee market. The maximum number of countries in which a company operates is higher for coffee (99 countries) compared to rice (37). The largest market share in the rice market is 3.35%, held by Wilmar International (table S.3 in supplementary material), while in the coffee market it was 11% in 2013 and increased to 13% in 2022, both attributed to Nestlé (table S.8). On average, the coffee market is dominated by larger players. The maximum share of total volume and total WF is the same in the coffee market, whereas the maximum share of WF is lower than that of volume in the rice market.

3.2. Companies' presence

About 10% of companies in the rice market operate in more than one country, with 2% of them operating in more than five countries. Among notable cross-national players are Scotti Riso (9 countries), Ebro Foods (19 countries), and Mars (37 countries) (figure 2 and table S.1). The coffee companies show a higher international presence, with approximately 18% of companies operating in more than one country, of which 6% are active in more than five countries. Key cross-national players in the coffee market include Illycaffè (30 countries), Lavazza (48 countries), JDE Peet's BV (61 countries), and Nestlé, present in all 99 countries in our sample (figure 2 and table S.2).

Figure 3 represents the lognormal distribution of the companies' shares in the rice and coffee markets[9]. In 2022, approximately 2% of the companies in the rice market held a share of the world total greater than 1% (see table S.3). Notable players in the rice market include Ebro Foods with a share of 1.58%, JA Group (Japan Agricultural Cooperatives) with a share of 1.60%, China National Cereals, Oils & Foodstuffs Imp & Exp Corp (COFCO) with a share of 2.76%, and Wilmar International with a share of 3.35%. Interestingly, JA Group only sells in Japan, while COFCO and Wilmar International operate solely in China. In contrast, Mars, which operated in 37 countries in 2022, held a share of only 0.9% of the world total for that year, while Riso Scotti, active in 9 countries, had a share of only 0.1%. Notably, among the significant cross-national players, Ebro (operating in 19 countries) is the only one with a share of the world total exceeding 1%.

In the coffee market, approximately 2.5% of companies held a share greater than 1%, but with a higher level of concentration compared to the rice market. Leading companies in the coffee market include Nestlé with a share of 13.5%, JDE Peet's BV with 10.3%, and Kapal Api Group with 6% (see table S.4). Nestlé and JDE Peet's not only lead in terms of market share but also in cross-national presence. In contrast, Kapal API Group primarily focuses on the Indonesian market. In these two markets, the intersection of

[8] Probably the temporary decline in coffee sales is due to reduced production in the same year, which, in turn, may result from a combination of off-biennial production cycles, unfavorable meteorological conditions, and increased fertilizer costs. Coffee presents a biennial production pattern in which plants alternate high-yielding and low-yielding years; the latter include reduced flower and fruit production. During the 2022/23 season, various coffee-growing areas presented this off-biennial cycle, generating diminished harvests (ICO 2023, Agaya 2023). Moreover, a post-pandemic general fall of disposable income could have affected the decrease in coffee sales (ICO 2023).

[9] The normal fit (over-log-transformed data) has been verified by considering a Kolmogorov goodness-of-fit test: the test statistics has been evaluated as the maximum absolute distance between the hypothetical cumulative distribution function and the empirical distribution function, multiplied by the square root of the sample size. The outcome is 0.809 for coffee and 0.591 for rice, which are below the 5% limit (0.886) for a normal distribution with both parameters estimated using the same sample being tested (Lilliefors 1967). The parent distribution for both samples of market shares can therefore be supposed to be a lognormal distribution, since in both cases the Kolmogorov test is passed at 5% significance level.

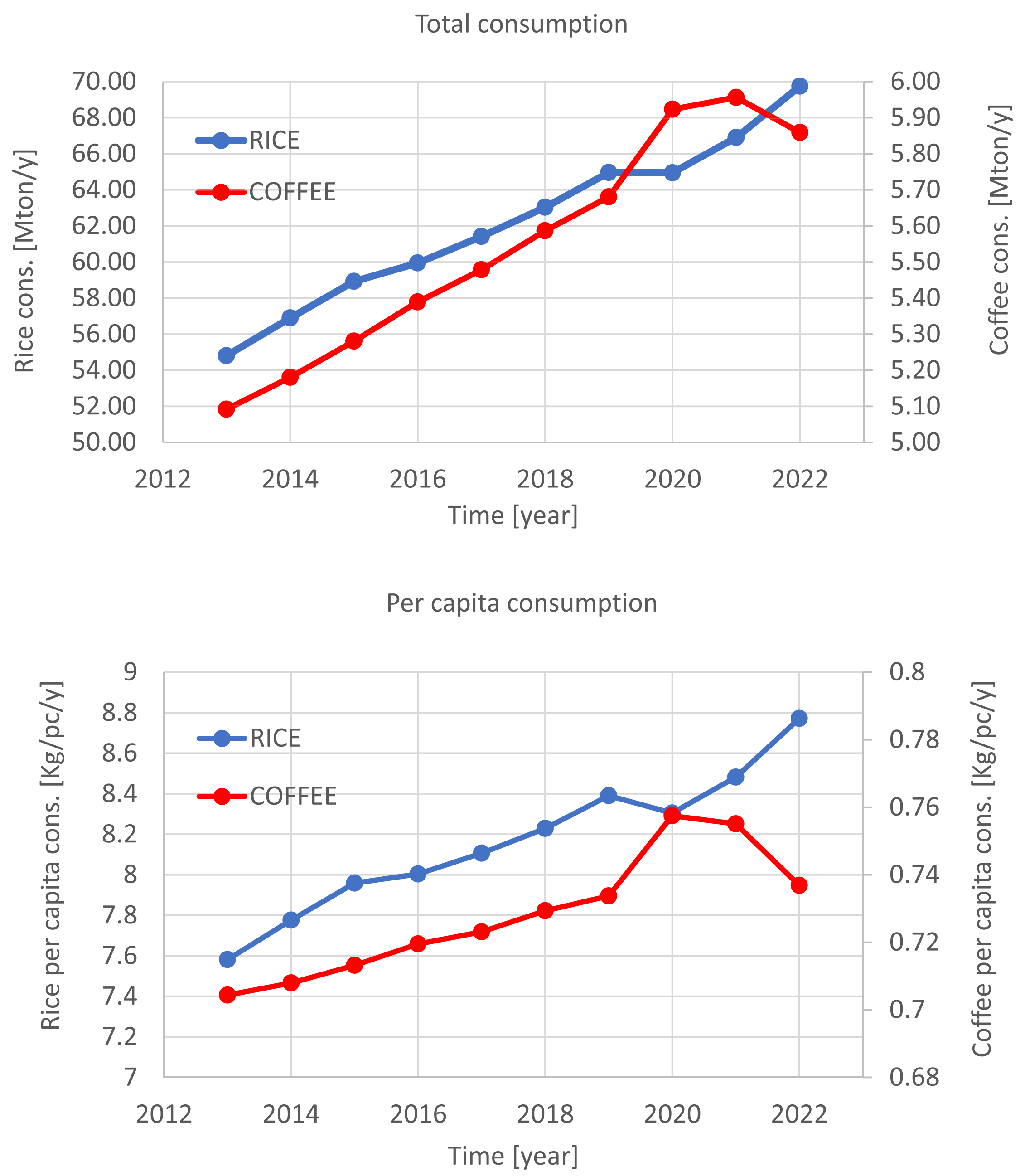


Figure 1. Trends in global volumes of rice and coffee consumption (2013–2022). Source: authors' elaboration on Euromonitor International data on sales (2023). Totals are calculated including 'others' and 'private labels' categories that encompass also small companies (with a market share below 0.1%) in each country.

internationalization and concentration takes unexpected trajectories. In the rice market, companies with the highest market concentration dominate in one single country each, while many more internationalized companies hold a low market share. On the other hand, large companies in the coffee market with the highest market shares operate in a significant number of countries.

In both the rice and coffee markets, many companies have consistently operated in a similar number of countries over time (tables S.5 and S.6). However, among the companies that have changed the number of countries where they sell, more have expanded their presence in multiple countries than have reduced their presence.

Figures 4 and 5 describe the evolution of companies' share of world total over 2013–2022. Most of the rice companies considered experienced a decrease in market share, while some saw a significant expansion (figure 4). China Resources Enterprise saw its share of rice sales increasing from 0.44% in 2013 to 1.57% in 2022, (table S.7). Wilmar International, a prominent Asian agri-business group based in Singapore, exhibited even stronger growth, with its share more than doubling from 1.14% in 2013 to 3.35% in 2022. Half of the coffee companies considered experienced a

Table 1. Total volume and total water footprint of supply for rice and coffee.

	Rice market			Coffee market		
year	Volume (10^3 tonnes)	WFs (km^3)	uWFs (m^3 ton^{-1})	Volume (10^3 tonnes)	WFs (Km^3)	uWFs (m^3/ton)
2013	54 807	98 840 158	1803	5092	80 064 201	15 724
2014	56 897	102 872 482	1808	5180	79 823 372	15 409
2015	58 927	104 719 426	1777	5280	85 122 220	16 120
2016	59 946	108 452 741	1809	5389	84 725 055	15 721
2017	61 413	111 694 954	1819	5478	86 405 014	15 773
2018	63 030	115 089 793	1826	5587	88 177 656	15 784
2019	64 961	119 116 218	1834	5681	89 677 611	15 787
2020	64 944	119 068 631	1833	5923	92 744 925	15 657
2021	66 904	123 240 235	1842	5956	93 434 872	15 688
2022	69 740	128 930 054	1849	5859	92 435 612	15 777

Source: authors' elaboration from Euromonitor International (2023) and Tamea *et al* (2021). Totals are calculated on all companies in the sample (see section 2 and table 2), including 'others' and 'private labels' categories that encompass also small companies in each country (market share below 0.1%). The average uWFs of these two products for the world is calculated as the ratio between total WF and total volume associated to the sales of all companies of our sample.

Table 2. Summary statistics.

	Rice market			Coffee market		
	2013	2016	2022	2013	2016	2022
Total number of companies	388	377	350	392	407	419
Total number of countries	77	78	77	99	99	99
Average n of countries per company	1.31	1.34	1.35	2.29	2.24	2.21
Max n of countries per company	41	40	37	99	99	99
Average n of companies per country	6.60	6.46	6.14	9.07	9.21	9.33
Max n of companies per country	15	15	16	20	21	22
Average share on total volume	0.11	0.11	0.12	0.18	0.18	0.17
Max share on total volume	2.94	2.51	3.35	11.15	11.61	13.52
Average share on total WF	0.11	0.11	0.12	0.19	0.19	0.18
Max share on total WF	1.85	1.81	1.93	11.45	11.56	13.23

Source: authors' elaboration from Euromonitor International (2023) and Tamea *et al* (2021). The number of companies is calculated excluding the categories 'others' and 'private labels'. Shares are calculated on totals including 'others' and 'private labels'.

decrease in market share from 2013 to 2022, while the other half saw an increase (figure 5). Nestlé SA started with a high share and observed a notable growth during this period, with its market share rising from 11.14% to 13.52%. Lavazza and Mayora Indah also experienced growth, with their market shares increasing from 1.71% to 2.54% and from 1.81% to 2.59%, respectively (table S.8).

In general, the coffee market showed less change in companies' shares over time with respect to the rice market, demonstrated also by the different correlation coefficients reported in figures 4 and 5.

To describe the concentration level of the rice and coffee markets, we calculate the Herfindahl–Hirschman index (HHI) of their respective world markets. The HHI is a widely used measure of market concentration, calculated by summing the squares of the market shares of all firms within the market. It is defined as:

$$HHI = \sum_{c=1}^{n} s_c^2 \ldots \tag{7}$$

where s_c is the market share of firm c on total world volume and WF[10]. Table 3 reports the HHI index for rice and coffee, showing that the coffee market is clearly more concentrated than the rice market. This index provides insight into how much of the total world market volume and WF are controlled by a

[10] See section 2 for further detail on firm shares on world totals. The HHI is maximized when one firm has a monopoly and minimized when all firms have equal market shares at the world level. It assumes values from 0 to 10 000. A HHI below 1500 represents an industry with low concentration level; a HHI between 1500 and 2500 indicates a moderate concentration level; a HHI above 2500 corresponds to a high concentration level. Finally, values above 8000 indicate that there is a dominant player in the world market of coffee or rice (Rhoades 1993).

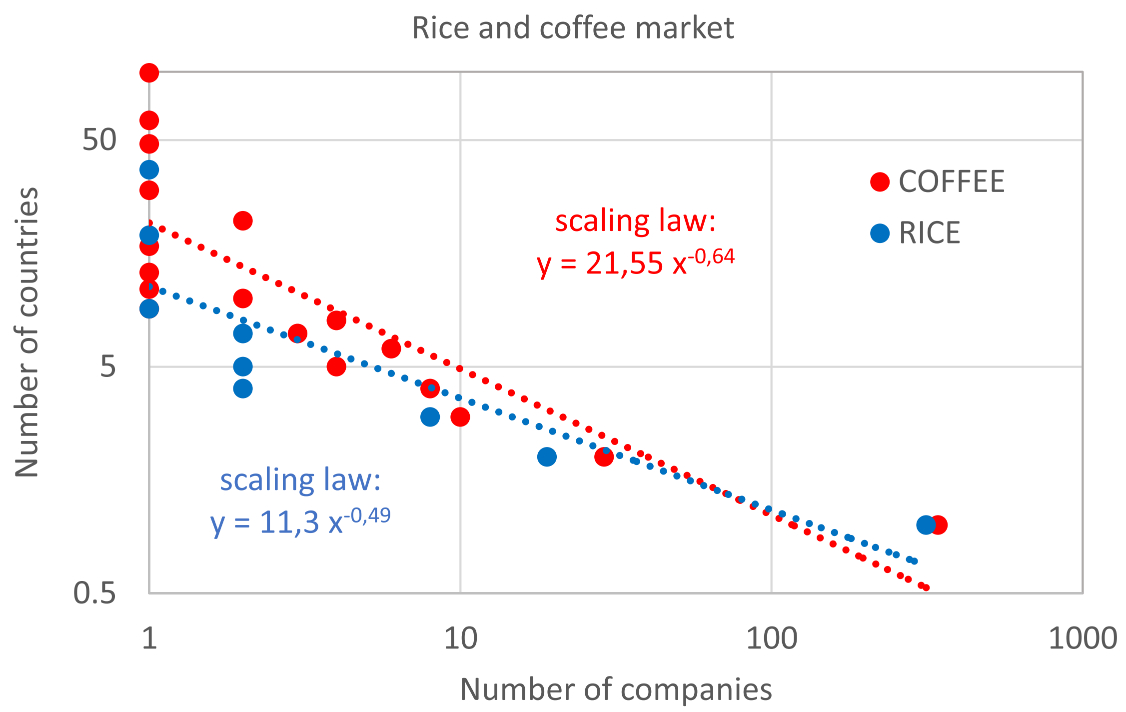


Figure 2. Distribution of companies' presence across countries (2022).
Source: authors' elaboration on Euromonitor International (2023). Categories 'others' and 'private labels' are excluded. The sample for 2022 includes 350 companies and 77 countries for rice, and 419 companies and 99 countries for coffee.

small number of companies or even a single dominant corporation.

Being our knowledge about the rice and coffee market distribution incomplete (due to the presence of the category labeled 'others' and 'private companies') we evaluate also the upper bound of HHIs by adopting the relations proposed by Naldi (2003) and Naldi and Flamini (2014), that provide rigorous bounds without assumptions about the statistical distribution of shares. We obtain very small increases compared to the HHI values calculated on the basis of known shares. The reason is due to the fact that, although the overall unknown market share is significant, it is made up of companies with very small shares and, therefore, not capable of significantly altering the value of the HHI. For this reason, the HHI values reported in this work can be considered practically coincident with the values that would have been obtained if the shares of the entire market had been known.

3.3. Virtual water analysis

Our analysis explores the significance of companies in relation to their WF, highlighting differences compared to volume. We consider the 3% of the companies in the rice market that held a share of more than 1% of the total WF in 2022 (figure 6 and table S.9). For some companies, their share of the world WF exceeds their share of the world volume. This suggests that resource concentration among large companies is often more pronounced in terms of virtual water than in terms of food volumes, emphasizing the importance of VW analysis. In the rice sector Padiberas Nasional holds a share of 1.38% of the world WF, notably higher than its 0.71% share in the world rice volume. Serba Wangi exhibits a 1.15% share in the world WF, more than double its 0.60% share in the world rice volume. Similarly, Ebro Foods, Mars Inc, and Alam Makmur Sembada also show higher shares of WF compared to volumes. Conversely, companies like Wilmar, COFCO, and China Resource Enterprise present an opposite situation.

Also in the coffee sector some companies' shares in the global WF surpass their shares in global volume (figure 7 and table S.10). For instance, Industrias Banilejas holds a 0.30% share in total volume but commands a 1% share in total WF, more than three times higher. This difference arises from the company's operations in the Dominican Republic, a country with a high uWF for coffee of approximately 50 000 m^3 ton^{-1}. Other companies exclusively operating in countries with elevated uWF values, such as Wings Corp, Java Prima Abadi, and Kapal Api Group, also demonstrate higher shares in WF than in volume, as they are all present in Indonesia, a nation with a uWF of around 30 000 m^3 ton^{-1} in 2022.

Mayora Indah is particularly noteworthy, having a 4.1% share in WF and a 2.5% share in volume. This company operates in multiple countries, including

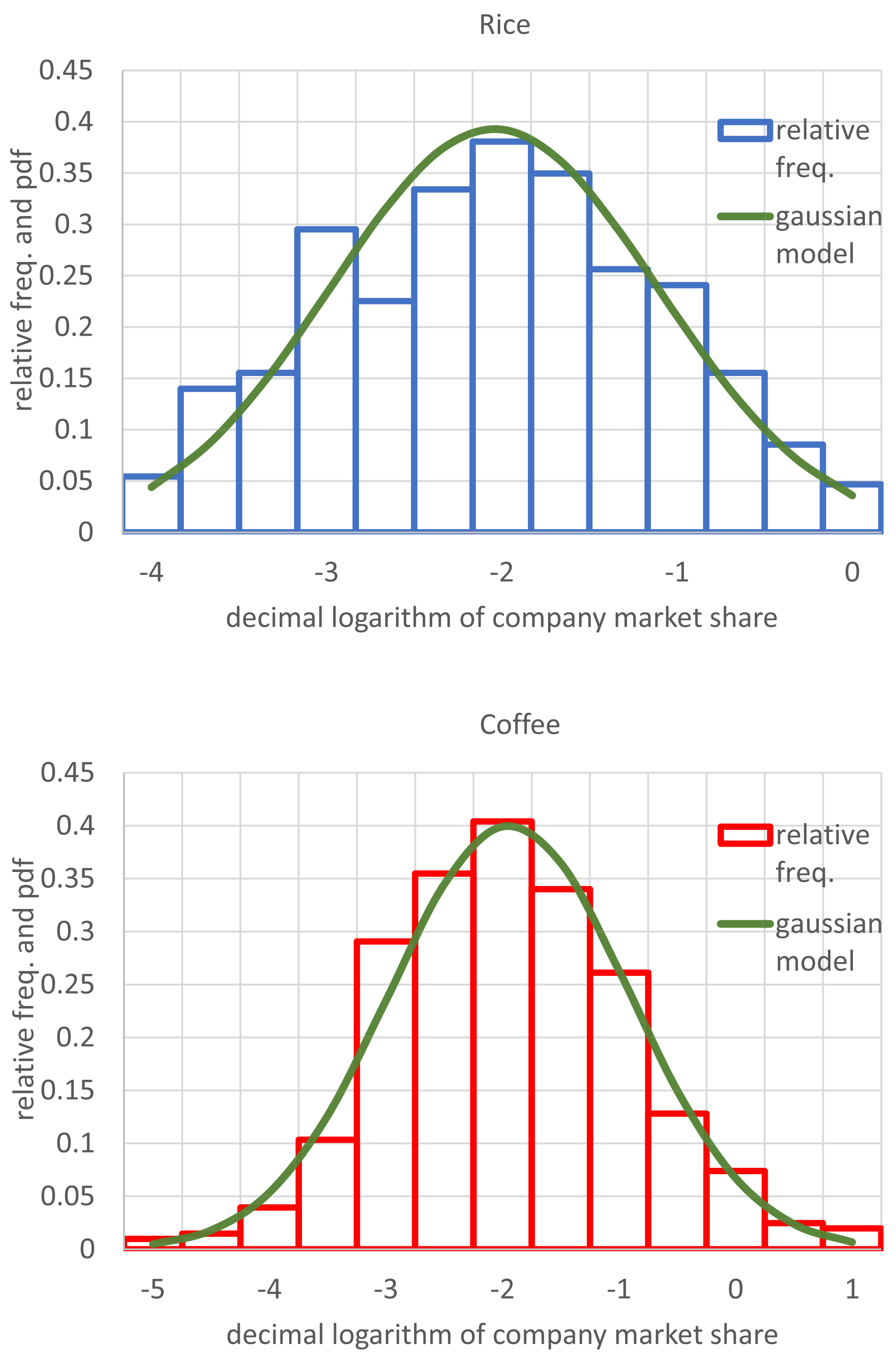
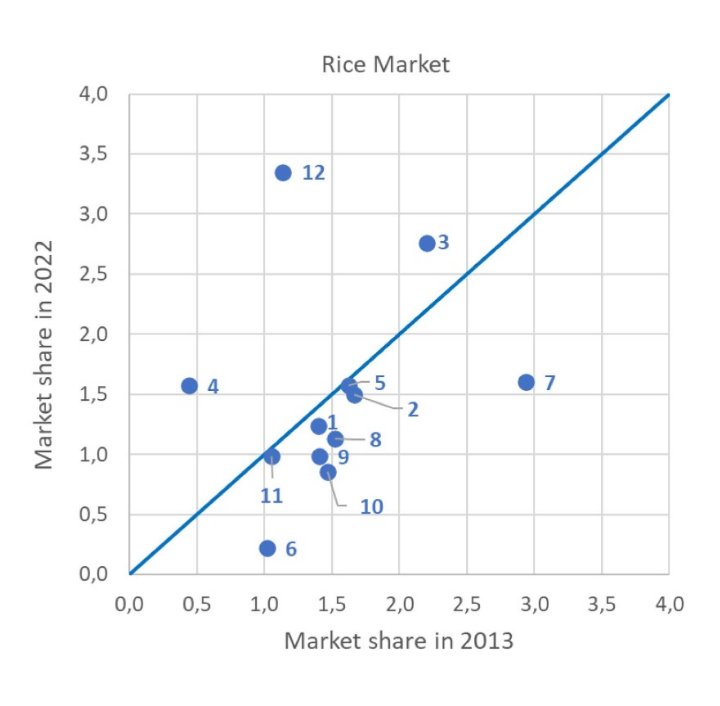


Figure 3. Distribution of companies' share on world volume, 2022.
Source: authors' elaboration on Euromonitor International (2023). Shares are calculated on totals including 'other' and 'private labels'. The parameters of the lognormal distribution have been estimated through the method of moments, applied to the log-transformed values of the shares. Values above the zero in log represent a market share above 1%. Negative log values represent a market share between 0% and 1%.

China, Malaysia, Indonesia, and the Philippines, maintaining a uWF of 25 000 m^3 ton^{-1}. Beside Mayora Indah, also Kapal Api Group exhibits a share in WF that is double with respect its share in volume. Comparing the coffee market with the rice market, we observe that in the former, a higher number of companies exhibit a higher share in WF than in volume, with this gap being, on average, larger than that in rice market companies.

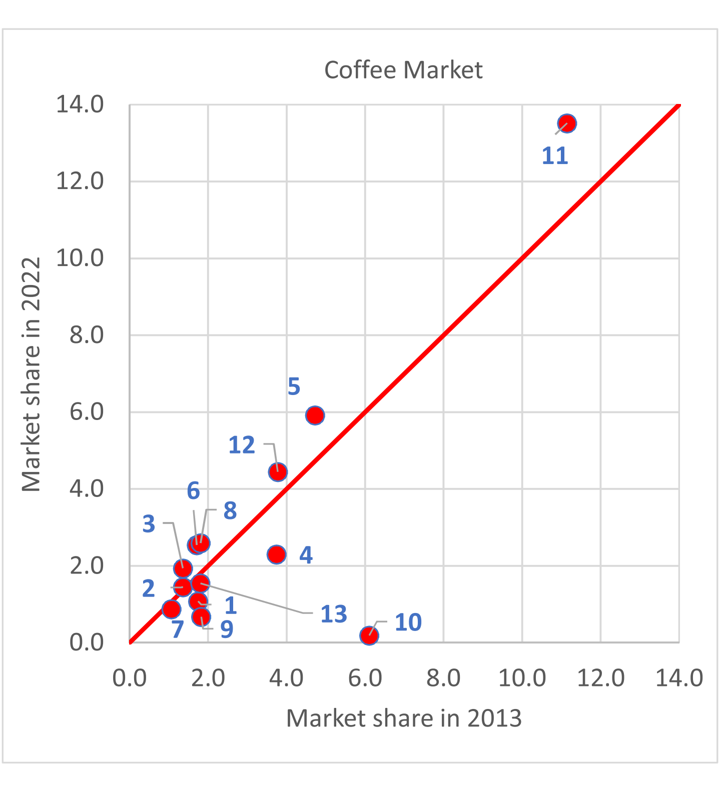
To assess the market concentration of each country in terms of VW for both rice and coffee, we computed the HHI using equation (7), where s_c is the market share of firm i on total country's WF[11]. In simpler terms, the HHI index is derived from the shares

[11] The total country WF is calculated including 'others' and 'private labels' (Euromonitor International 2023).



	Company Name
1	Al Doha Co for Processing & Distribution
2	Camil Alimentos SA
3	China National Cereals, Oils & Foodstuffs Imp & Exp Corp (COFCO)
4	China Resources Enterprise Ltd
5	Ebro Foods SA
6	Heilongjiang Agriculture Co Ltd
7	JA Group (Japan Agricultural Cooperatives)
8	Josapar-Joaquim Oliveira SA Participações
9	Mars Inc
10	National Agricultural Cooperative Federation
11	Pirahy Alimentos Ltda
12	Wilmar International Ltd

Figure 4. Changes between shares in 2013 and 2022 of relevant companies in the rice market. Source: authors' elaboration on Euromonitor International (2023). Shares are calculated on totals including 'other' and 'private labels'. Only companies with a sale share greater than 1% either in 2013 or in 2022 are included in the figure. Correlation coefficient between shares in 2013 and in 2022: 0.2.



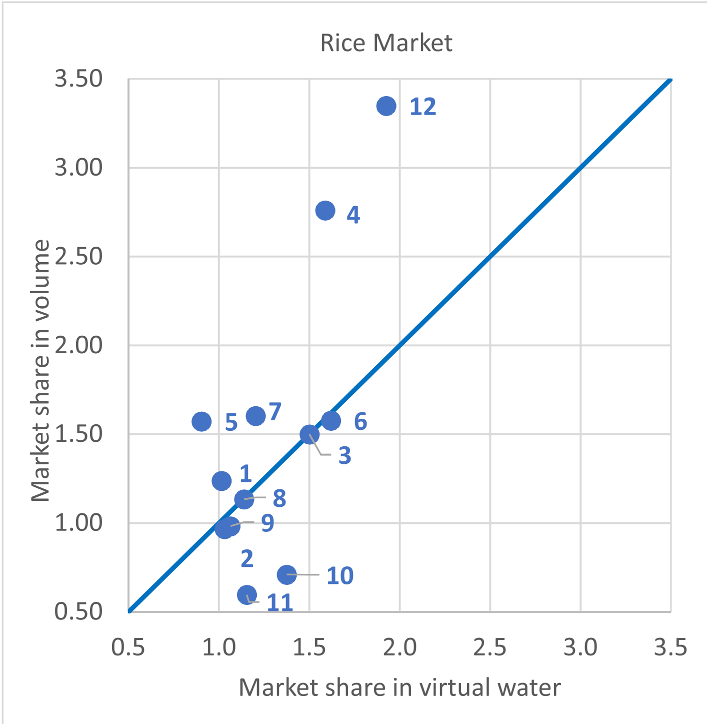
	Company Name
1	Dongsuh Foods Co Ltd
2	Indústrias Alimentícias Maratá Ltda
3	Java Prima Abadi PT
4	JM Smucker Co, The
5	Kapal Api Group
6	Lavazza SpA, Luigi
7	Massimo Zanetti Beverage Group SpA
8	Mayora Indah Tbk PT
9	Melitta Unternehmensgruppe Bentz KG
10	Mondelez International Inc
11	Nestlé SA
12	Strauss/São Miguel
13	Tchibo GmbH

Figure 5. Changes between shares in 2013 and 2022 of relevant companies in the coffee market. Source: authors' elaboration on Euromonitor International (2023). Shares are calculated on totals including 'other' and 'private labels'. Only companies with a sale share greater than 1% either in 2013 and in 2022 are included in the Figure. Correlation coefficient between shares in 2013 and in 2022: 0.8.

Table 3. Evolution of the HHI index for the world markets of rice and coffee.

	Rice		Coffee	
Year	*hhi vol*	*hhi WF*	*hhi vol*	*hhi WF*
2013	38	32	281	316
2014	41	33	285	334
2015	39	32	335	371
2016	41	33	323	377
2017	43	34	346	394
2018	43	34	370	418
2019	44	35	373	422
2020	45	33	376	417
2021	44	32	377	421
2022	43	31	380	429

Source: authors' elaboration from Euromonitor International (2023) and Tamea *et al* (2021).

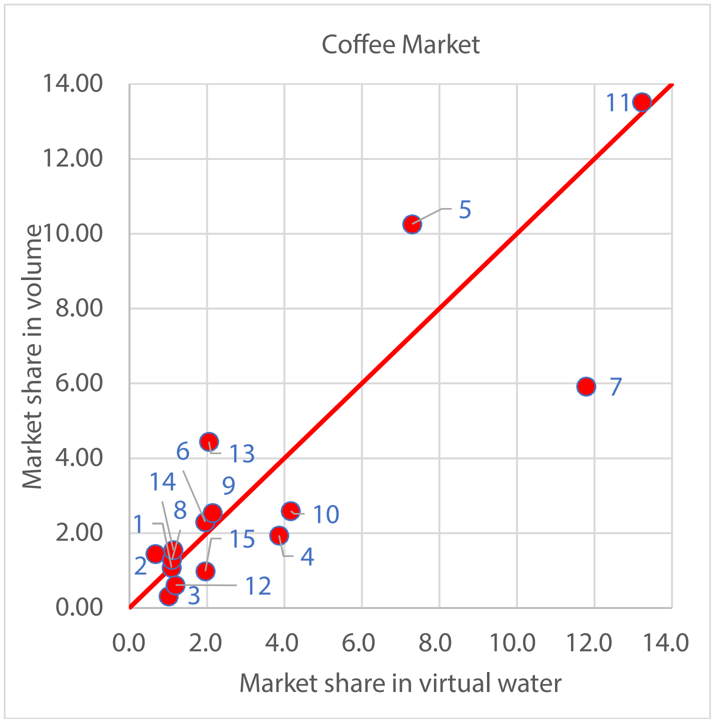


	Company Name
1	Al Doha Co for Processing & Distribution
2	Alam Makmur Sembada PT
3	Camil Alimentos SA
4	China National Cereals, Oils & Foodstuffs Imp & Exp Corp (COFCO)
5	China Resources Enterprise Ltd
6	Ebro Foods SA
7	JA Group (Japan Agricultural Cooperatives)
8	Josapar-Joaquim Oliveira SA Participações
9	Mars Inc
10	Padiberas Nasional Bhd (BERNAS)
11	Serba Wangi Sdn Bhd
12	Wilmar International Ltd

Figure 6. Correlation between companies' share on world rice WF and volume, 2022.
Source: authors' elaboration from Euromonitor International (2023). Shares are calculated on totals including 'other' and 'private labels'. Only companies with a sale share greater than 1% are included in the figure.

of firms in the total VW associated with the volume of rice and coffee sold within a country. It quantifies the level of concentration of VW within that country. High HHI values (above 2500) suggest that a few firms dominate the control of water resources associated with rice or coffee sales on a national scale. A higher HHI suggests a more concentrated market, potentially indicating reduced competition and increased market power among selected few firms. Conversely, low values (below 1500) indicate a more evenly distributed control of water among all active firms in the country. This may imply a more competitive market with a broader distribution of market share among multiple players. Approximately 14% of the countries in the rice market exhibit an HHI exceeding 2000, indicating a medium-high concentration level (figure S.1). Figure 8 depicts the geographical distribution of these countries. Nigeria, New Zealand, Canada, North Macedonia, and Spain have an index ranging from 2000 to 3000. Australia, Pakistan, and Tunisia fall within the 3000–4000 range. Guatemala has an index of 6700, while Uzbekistan has an index of 8500.

Table S.13 presents the companies' shares in countries where the HHI exceeds 2000 in 2022. All these countries show at least one company's market share



	Company Name
1	Dongsuh Foods Co Ltd
2	Indústrias Alimentícias Maratá Ltda
3	Industrias Banilejas CxA
4	Java Prima Abadi PT
5	JDE Peet's BV
6	JM Smucker Co, The
7	Kapal Api Group
8	Kraft Heinz Co
9	Lavazza SpA, Luigi
10	Mayora Indah Tbk PT
11	Nestlé SA
12	Sari Incofood Corp PT
13	Strauss/São Miguel
14	Tchibo GmbH
15	Wings Corp

Figure 7. Correlation between companies' share on world coffee WF and volume, 2022.
Source: authors' elaboration from Euromonitor International (2023) and Tamea *et al* (2021). Shares are calculated on totals including 'other' and 'private labels'. Only companies with a sale share greater than 1% are included in the figure.

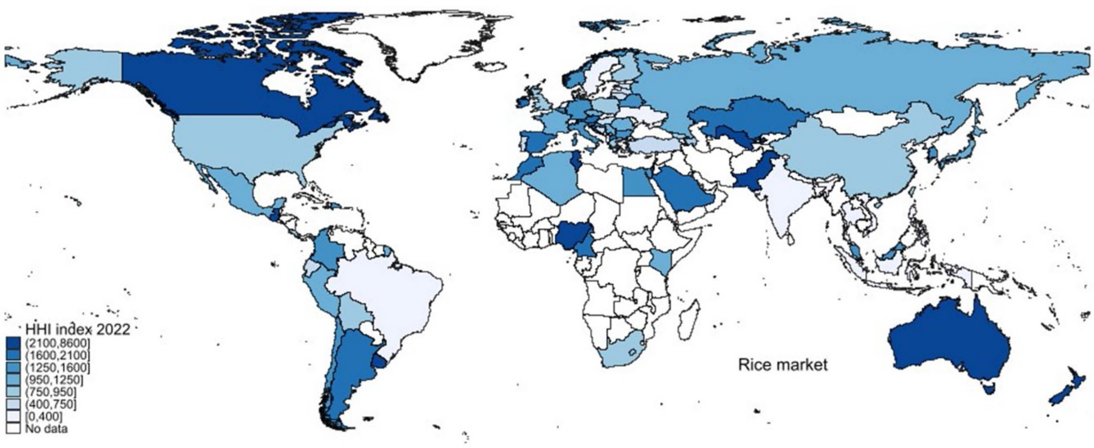


Figure 8. Countries HHI index (rice market, 2022).
Source: authors' elaboration from Euromonitor International (2023) and Tamea *et al* (2021).

on the total rice WF sales exceeding 40%, indicating very high market power and concentration. In Guatemala, for instance, Arrocera Los Corrales dominates the market, accounting for over 80% of total rice sales. Similarly, in Uzbekistan, Generics have a 90% share of the rice market.

Half of the countries with an HHI over 2000 increased their rice market concentration from 2013 to 2022, while the other half decreased it (figure S.2). Israel more than doubled its HHI score from 2036 in 2013 to 4079 in 2022. Table S.11 presents HHIs for all countries in our sample from 2013 to 2022. In 2022, 13 countries had an HHI between 1500 and 2000, indicating a moderate level of market concentration, such as in Egypt, Cameroon, and Morocco. Moreover, most countries worldwide increased their concentration index over time, with exceptions like India, Vietnam, and Taiwan, which decreased their

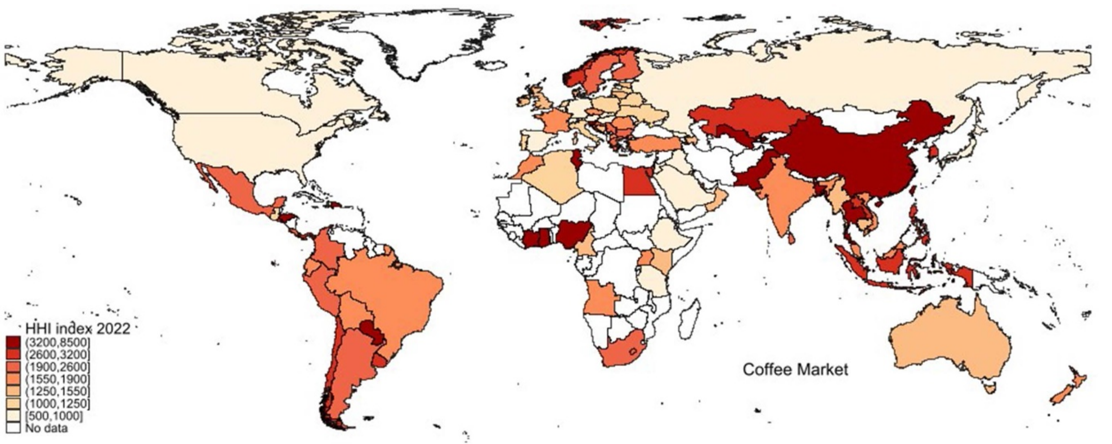


Figure 9. Countries HHI index (coffee market, 2022).
Source: authors' elaboration from Euromonitor International (2023) and Tamea *et al* (2021).

HHI score from 2013 to 2022, suggesting a rise in the diversification of enterprises active in the rice market in these countries.

In the coffee market, approximately 40% of countries have an HHI greater than 2000, with 20% having an index greater than 3000 (figures 9 and S.3), such as China, Honduras, and Côte d'Ivoire. The markets with the highest concentration levels are Nigeria (HHI: 8549), Ghana (HHI: 7657), and Bangladesh (HHI: 6776). Nigeria has maintained a very high level of concentration since 2013, Ghana significantly increased its HHI score from 2013 to 2022, while Bangladesh experienced a decrease during the same period (figure S.4 and table S.12).

Table S.14 shows the companies' share in countries where the HHI exceeds 3000 in 2022. Many of these nations have a company's market share on the total WF associated with coffee sales exceeding 50%. Notably, in Bangladesh, Nestlé dominates the market, accounting for over 80% of total coffee sales. Similarly, in Ghana, Nestlé holds a substantial 87% share, while in Nigeria, it commands a significant 92% of the total coffee market. Noteworthy companies holding a share higher than 50% in a single country include Industrias Banilejas in the Dominican Republic, Gabriel Kafati in Honduras, Casa Luker in Panama, Atlantic Grupa in Slovenia, Dongsuh Foods in South Korea, Amen Group in Tunisia, and Food Empire Holdings in Uzbekistan. Ghana's and Paraguay's indexes saw a massive increase overtime. However, the majority of countries actually decreased their HHI index from 2013 to 2022 (figure S.4). Thirty five countries have an HHI score between 1500 and 3000, indicating a medium market concentration level (table S.12). The coffee market country HHI indexes present more diverse values compared to those in the rice market. Moreover, changes over time are more dynamic than in the rice market.

4. Discussion

Findings indicate that only a few companies hold a share of total world volume higher than 1%. Despite their small number, these companies collectively wield considerable influence. In the rice market, 16% of the total WF associated with rice worldwide in 2022 (equivalent to 20 017 000 000 m^3 of VW) was controlled by the top 12 companies selling the highest rice quantities in our sample countries, including Wilmar International, Ebro Food, Camil, and Mars. In the coffee market, the concentration of water resources in the hands of large companies is much more pronounced. The top 15 companies in 2022 held together 55% of the total WF associated with roasted coffee worldwide in that year (corresponding to 50 507 400 000 m^3 of VW), including Nestlé, Lavazza, Tchibo, Kapal, JDE, and Kraft Heinz. These findings remain consistent over the 2013–2022 period, indicating relatively stable water concentration trends at the large company level for both products.

Furthermore, comparing the role of large companies to states' figures, we observe that in 2022, the VW associated with coffee sold by Nestlé alone worldwide (over 12 billion m^3) is approximately six times higher than the total VW quantity associated with coffee imports for France (about 2 billion m^3), the largest importer in that year. Similarly, the VW amount related to Kapal is five times higher than France's coffee import quantity in the same year. Although VW in the rice market is less concentrated in the hands of one or two enterprises, in 2022, the amount associated with the large rice companies group (the top 12 companies with a world share in sales higher than 1%, encompassing about 20 billion m^3) is approximately one and a half times higher than the VW quantity associated with the three largest rice importers, namely the Philippines, China, and Iraq, in the same year (about 15.5 billion m^3 for the three countries combined).

Additionally, our analysis reveals that in the coffee market a high number of companies hold a higher product share in terms of WF than in terms of volumes. This number of companies is higher than the one in the rice market presenting an analogous situation. The group of large companies (having a respective world share of sales above 1%) holds a share of WF that is 7.5% higher than the share in volumes, showing a higher gap with respect to the large companies of the rice case (table S.10). However, this average gap reveals larger differences if single cases are observed. Industrias Banilejas, a large company engaged in coffee processing and trade that was founded in 1945 in the Dominican Republic, holds a world share of WF associated to its sold coffee that is almost 4 times higher than its corresponding share in volumes.

Java Prima Abadi, Wings, Sari Incofood, and Kapal have their respective shares in WF that are double than their corresponding shares in volumes, with Kapal controlling a 6% of the volumes of coffee sold in the world, but a 12% of the WF associated to the sold coffee worldwide. This suggests that large companies in the coffee market hold on average larger shares of VW associated to the product they sell with respect to rice companies, suggesting a lower degree of water-related sustainability along the value chain and a stronger control directly and indirectly exerted on water resources.

Finally, according to the HHI metrics, the coffee market is more concentrated than the rice market, for 2022. In the coffee case concentration in the hands of few large companies is more pronounced in terms of VW than in volumes, and this gap increased from 2013 to 2022, while for the rice case the contrary occurs. In the coffee market 40% of countries have a high concentration degree internally, while for the rice this happens only for 14% of the sample countries. In the coffee case we notice also a higher number of countries with a moderate HHI, while for rice only 13 countries present this condition. In the coffee case we observe more dynamicity in terms of country increasing and decreasing sale concentration by large companies overtime. In countries with very high HHI in the coffee market, Nestlè evidently dominates the scene, with market shares ranging between 2.63% in the Dominican Republic and 92% in Nigeria. Results on market concentration for coffee are in line with previous research (Bulte *et al* 2018, Falsetti *et al* 2020).

Large agri-food corporations present interesting dynamics of expansion and market concentration. Since the late 1980s companies such as Nestlé and Kraft diversified their control over brands by conducting acquisitions in different markets, also influenced by financial investors. Firms started to make vertical (with suppliers and customers) and horizontal (with direct competitors) acquisitions within the same subsector[12] (Chemnitz *et al* 2017, Scoppola 2021). In the coffee market large companies pursued a strategy of both generalization (managing a wide range of products) and specialization in particular market segments, enlarging therefore their outreach. Food manufacturers established linkages with upstream actors, such as large commodity traders, and downstream food retailers. Therefore, the core of competition was shifting from being among companies to taking place among value chains. Moreover, the modern retailing sector—hypermarkets and discount stores—plays a major role in the food value chain. By choosing suppliers and the kind of consumer targets, they influence food production conditions as well. They rely on large corporations that reach economies of scale, meet quality standards, and intervene in postharvest activities, such as processing and packaging. Consequently, industrial agriculture is indirectly promoted, and rice and coffee are among the main products involved in these trends. Finally, many countries create economic spaces with less strict tax and environmental standards in order to attract investments in the agribusiness with the promise to foster agricultural development. For example, Monsanto, Cargill, Nestlé and other agri-food companies have been in partnership with the Tanzanian government in an investment zone, with the argument of improving small farmers' access to modern technology (Chemnitz *et al* 2017).

There is strong evidence on the environmental harm that industrial food production, processing and distribution exerts through high GHG emissions and unsustainable water and land management, with detrimental effects also on biodiversity (Chanakya and De Alwis 2004, Kebede *et al* 2010, Chemnitz *et al* 2017, Scoppola 2021). For example, in some areas of the world industrial agriculture impacted soil fertility with a consequent drop in rice yield (Chemnitz *et al* 2017). Large monocultures also reduce the carbon-sink capacity of vegetation and bio-diverse habitats (Oxfam 2013). Moreover, through either expropriation or direct influence on large land surfaces large corporations negatively influence land and water rights of local populations (Dell'Angelo *et al* 2018). Finally, since large companies invest more on expanding the production and processing quantity than in efficiency, scholars estimated high levels of food waste, along with the related embedded VW (Chemnitz *et al* 2017). Oxfam (2013) argues that none of the 10 world most powerful food and beverage companies—Associated

[12] Examples of the joint efforts of financial investors and corporation strategies are the emergence of the group Anheuser-Busch, of the Kraft Heinz Company and of the JAB Holding. The latter is an investment company belonging to the German Reimann family, that controls major coffee brands such as Jacobs Douwe Egberts, Caribou and Keurig Green Mountain. JAB regularly challenges the Nestlé dominant position in the international coffee market (Chemnitz *et al* 2017).

British Foods (ABFs), Coca-Cola, Danone, General Mills, Kellogg, Mars, Mondelez International (previously Kraft Foods), Nestlé, PepsiCo and Unilever—have adequate policies to protect local communities from land and water acquisitions along their supply chains (Oxfam 2013). There is evidence of controversial practices of freshwater pollution by Nestlé operations in Nigeria, among others (Abba 2019). However, despite high attention is usually placed on unsustainable social and environmental practices of Nestlé operations, according to the score created by Oxfam (2013), the lowest degree of water sustainability practices among the largest ten food and beverage companies are attributed to Mars, Mondelez and ABF.

Regarding the rice market, the State-led Chinese COFCO had a strong expansion during the last decade and replaced the 'ABCD' dominance especially in the staple food trade from Brazil (Chemnitz *et al* 2017). Environmental impacts of extensive and intensive rice cultivation derive mainly from mechanization and fertilizers use, and they are related to climate change, ozone depletion, terrestrial acidification, freshwater and marine eutrophication and fossil depletion (Fusi *et al* 2014).

5. Conclusion

This work has provided estimates of the amount of VW controlled by large agri-food companies and of the level of concentration of this metric that are crucial in order to understand the extent of companies' influence on a fundamental natural resource such as water. This also helps policy-makers to identify large enterprises as crucial actors in water management policies. The main limitation pertains the limited data currently available on the actual place of production of the rice and coffee that is sold by the multinational companies in our sample, that typically obtain their products from multiple production sites. This information could be obtained by delving deeper into individual cases of large corporations or specific products, as done in the TRASE project (SEI 2020). Additionally, there is a lack of information on the trends of the companies included in the categories of 'others' and 'private labels.'

Future lines of research include econometric analysis of the correlations between each country's HHI for food volumes and the associated WF and some country features that may influence the level of food market concentration for staple and cash crops, such as the domestic level of economic freedom, trade policies, anti-trust policies, and the structure of the food and agricultural value chains. Moreover, more nuanced and detailed research is needed on the environmental impact of large corporations operating in the rice and coffee markets. Finally, we aim at exploring the role of large agri-food companies for other food items, in terms of volumes and WF, predicting also trends in the future.

Data availability statement

The Euromonitor Passport data cannot be made publicly available upon publication because they are owned by a third party and the terms of use prevent public distribution. The Euromonitor data that support the findings of this study are available upon reasonable request from the authors. The data of the CWASI Water Footprint database are publicly available.

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Authors contribution

A B: Conceptualization, Methodology, Data analysis, Investigation, Writing and Editing. E V: Conceptualization, Methodology, Investigation, Writing and Editing, Supervision, Funding acquisition. S D: Conceptualization, Methodology, Investigation, Writing and Editing, Supervision, Funding acquisition. L R: Conceptualization, Methodology, Data Analysis, Investigation, Writing and Editing, Supervision, Funding acquisition. F L: Conceptualization, Methodology, Data Analysis, Investigation, Writing and Editing Supervision, Funding acquisition.

Conflict of interest

The authors declare no competing interests.

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