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Sustainability assessment of commercial Brazilian organic and conventional broiler production systems under an Emergy analysis perspective

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ABSTRACT

This study aimed at assessing and comparing the sustainability of a Brazilian production unit representing the production of broilers reared in an organic system (*UPrO*) with a handling unit for the production of broilers reared in a conventional system (*UPc*) based on Emergy analysis. The analysis was carried following four steps: (i) definition, location, and data collection of broiler production units; (ii) Emergy diagram drawing; (iii) Emergy table construction; and (iv) result assessment according to the Emergy indicators in the graphical tools. According to the results, *UPrO* showed better environmental performance than *UPc* while *UPc* showed better productive efficiency. However, the Emergy Sustainability Index (*ESI*) results indicated that *UPrO* is sustainable in the short term, while *UPc* is unsustainable. Also, it is possible that the best environmental performance by *UPrO* is at the limit for systems specialized in the broiler production with a high-intensification degree. Since the corn and soybean meal were the inputs that most contributed to the total Emergy for both systems, and the yield comes from less concentrated sources of energy, the decision-making should be focused on to improve the environmental performance of the commercial broiler production systems being directed towards the reduction of the environmental load, from the use of ingredients with higher renewability(*R*%), i.e. organic corn and soybean feed usage.

1. Introduction

Concerns about the exploitation and destruction of natural resources have raised awareness of environmental protection and encouraged “green consumption” (Moisander, 2007). According to Chekima et al. (2019), in the last 15 years, organic agriculture and consumption practices have gained interest from society, as they support the health of people and environment. Following this trend, interest in organic chicken meat has also shown growth in recent years. According to Eurostat data (2021), the production of organic broiler in European countries showed an average annual growth of 1% between the years 2012 and 2019, and in the United States sales of organic chicken meat raised from USD 371.5 million to USD 1.12 billion in 6 years (NASS, 2021)-a 33% increase in the amount collected.

In fact, the Brazilian commercial broiler industry is one of the most important animal protein chains in the world. According to the FAO database, Brazil is the third-largest chicken producer and the world leader in chicken exportation. From 2010 to 2020, the Brazilian commercial broiler industry produced 139 million tons and exported 41 million tons of chicken meat (FAOSTAT, 2021). However, there are no official statistical data regarding the Brazilian organic broiler production. According to Korin®’s sustainability report, one of the most important Brazilian organic chicken producer enterprises, the sale of organic chicken showed an increase of 4% in revenue from 2018 to 2019 (Korin, 2019).

Compared to other livestock systems, the broiler production has been usually identified as environmentally efficient (A. G. A. G. Williams et al., 2006). However, is organic broiler production more sustainable

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than conventional broiler production? Despite being more environmentally efficient than the livestock systems, the search for the most sustainable system amongst the existing broiler systems is needed.

Several studies in the scientific literature suggest assessing the broiler sustainability. This studies compare the organic and conventional broiler production using the Life Cycle Assessment approach (LCA) (Bokkers and de Boer, 2009; Leinonen et al., 2014, 2012; Van Der Werf and Salou, 2015; A G A G Williams et al., 2006). More recently, van Wagenberg et al. (2017) systematized and analyzed the results of peer-reviewed studies published in the main scientific databases for different categories of livestock in both organic and conventional systems. The LCA is a meaningful tool to assess resources, energy and human services in the same quantitative boundary (Brown and Buranakarn, 2003). As a great advantage, LCA can quantitatively appraise environmental impacts generated by livestock production systems (Wang et al., 2020). However, the indicators and rankings resulting from LCA are presented in several units (i.e., CO_2, energy consumed, human capital required, etc.), making the results difficult to be compared to other studies (Brown and Buranakarn, 2003). In addition, ecosystem services and resources provided "for free" by the environment are often ignored by LCA, and it could limit the understanding of the method (Liu et al., 2018).

The assessment of the broiler production sustainability as a whole should to consider all the contributions of the environment. This assessment need to consider a framework that comprises the economic and ecological interactions. Emergy synthesis enables the conversion of different units (kg, g, L, $, bits) from diverse inputs (ecosystem resources and services, materials, constructions and infrastructure, services and information) and different dimensions into a unit of universal measure: the solar emjoules (seJ) (Odum, 1996). The Emergy synthesis assesses the process from the point of view of the "donor". The use of the Emergy indicators make possible the sustainability assessment by: (i) to distinguish the dependence of different inputs and (ii) to assess the environmental system resources; and (iii) to assess the hierarchical energy levels of the components (Yang et al., 2019), as well as to evaluate the resilience of the production system (Agostinho et al., 2019). According to Castellini et al. (2012), LCA is a reliable tool to environmental impact assessment from a multidimensional perspective whereas the Emergy synthesis is a better way to evaluate the exploitation level and resources availability. Thus, considering the resource availability and their efficient use as a part of sustainable development (SDG, Goal 12.2), Emergy synthesis could be interesting for the broiler sustainability assessment purpose.

A couple of studies in the scientific literature aim to assess the sustainability of poultry production systems adopting Emergy synthesis (Allegretti et al., 2018; Castellini et al., 2006, 2012; Cheng et al., 2017; Guan et al., 2016; Zhang et al., 2013). Among those, Castellini et al. (2006) compared organic and conventional broiler production systems based on European organic production legislation and experimental conditions. However and to our knowledge, there is no study in the scientific literature that aims at comparing of productions at a commercial level and from the Emergy approach. Thus, this study aimed at assessing and comparing the sustainability of a Brazilian production unit representing the production of broilers reared in an organic system (*UPrO*) with a handling unit for the production of broilers reared in a conventional system (*UPc*) based on Emergy analysis.

2. Material and methods

The study was carried at the Laboratory of Socioeconomic and Animal Science from School of Veterinary and Animal Science, University of São Paulo, Pirassununga, Brazil, from October 2020 to June 2021, approved under protocol number 1303010221 by the Committee of Ethics in the Use of Animals, School of Veterinary and Animal Science, University of São Paulo (CEUA-FMVZ/USP).

2.1. Case selection and data from organic and conventional production systems

The methodology was divided into two stages:

i) definition of the representative production unit (*UPrO*) for broiler produced in an organic system - defined by the technical staff of the agroindustry: to this purpose, the technical staff of the agroindustry was queried regarding the technological package contained in a *UPrO* (feeders, drinkers, air conditioning system) as well as management intrinsic to production along with zootechnical indices.
ii) indication of a *UPrO* for a case study that were consistent with the characteristics determined in the first stage. For this, a unit was identified from the responses obtained in the questionnaire. Based on the definition of the *UPrO*, a broiler production system was selected with a technological package similar to the *UPrO*, aimed at the conventional broiler production system (*UPc*).

The boundaries of *UPrO* and *UPc* were defined as the area used for broiler production (*UPrO* = *buildingUpaddock*; *UPc* = *building*). Subsequently, questionnaires were remotely applied to the producers to raise quantitative data on the economic cost of production as well as information about zootechnical performance indicators.

2.2. Location, characteristics, and performance of production units

The *UPrO* selected for the study is located in Pirassununga, São Paulo, Brazil (Lat −21.9980468 S, long - 47.4280861, W; https://www.gps-coordinates.net/). The *UPc* was located in São José do Rio Preto mesoregion, São Paulo, Brazil (Lat −20.7836955S, long −49.8149752, W; https://www.gps-coordinates.net/). Both *UPrO* and *UPc* presented automated feeding and drinkers, heating from a wood-fired oven, and cooling using a combination of ventilation (positive pressure) and nebulization (Fig. 1).

Aspects related to housing and animal performance for *UPrO* e *UPc* are described on Table 1. Regarding animal density, the *UPrO* presented 9 birds/m^2 (5.0m^2/bird) for the covered area and 1.80 birds/m^2 for the paddock area (0.5m^2/bird), respecting the provisions of the Normative Instruction No.46, and Ordinance No.52 (BRASIL, 2021), which establish a maximum density of 0.4m^2/bird of paddock and 30 kg/m^2 for the covered area (~12 birds/m^2, considering birds with 2.50 kg of live weight). Access to the paddock area starts on the 21st housing day. For *UPc*, density was 11 birds/m^2 (0.09m^2/bird).

The poultry lineage produced was characterized as fast-growing for both *UPrO* and *UPc*, being slaughtered at ~45 days, generating 69,850 and 145,000 birds/yr, respectively. The average feed intake was 4.43 kg and 4.61 kg of feed during the entire housing period. Total weight gain was 2.4 kg and 2.5 kg, and total mortality was 3% and 1%, respectively. In both systems, the estimated feed conversion was 1.8:1.0 kg of live weight. Corn and soybean meal were the ingredients with the highest participation on the diets, representing 58% and 31% and 65% and 31%, for *UPrO* and *UPc*, respectively.

2.3. Model development in emergy analysis

The rules describing the "algebra" of emergy were:

- All sources of emergy of a process are attributed to the outputs of the process;
- Co-products of a process have the total emergy assigned to each pathway;
- When pathway splits, emergy is assigned to each "step" of the split based on its percentage of the total emergy flow in the pathway;
- The emergy of a system cannot be doubly counted: (a) emergy feedbacks cannot be doubly counted; (b) the outputs when

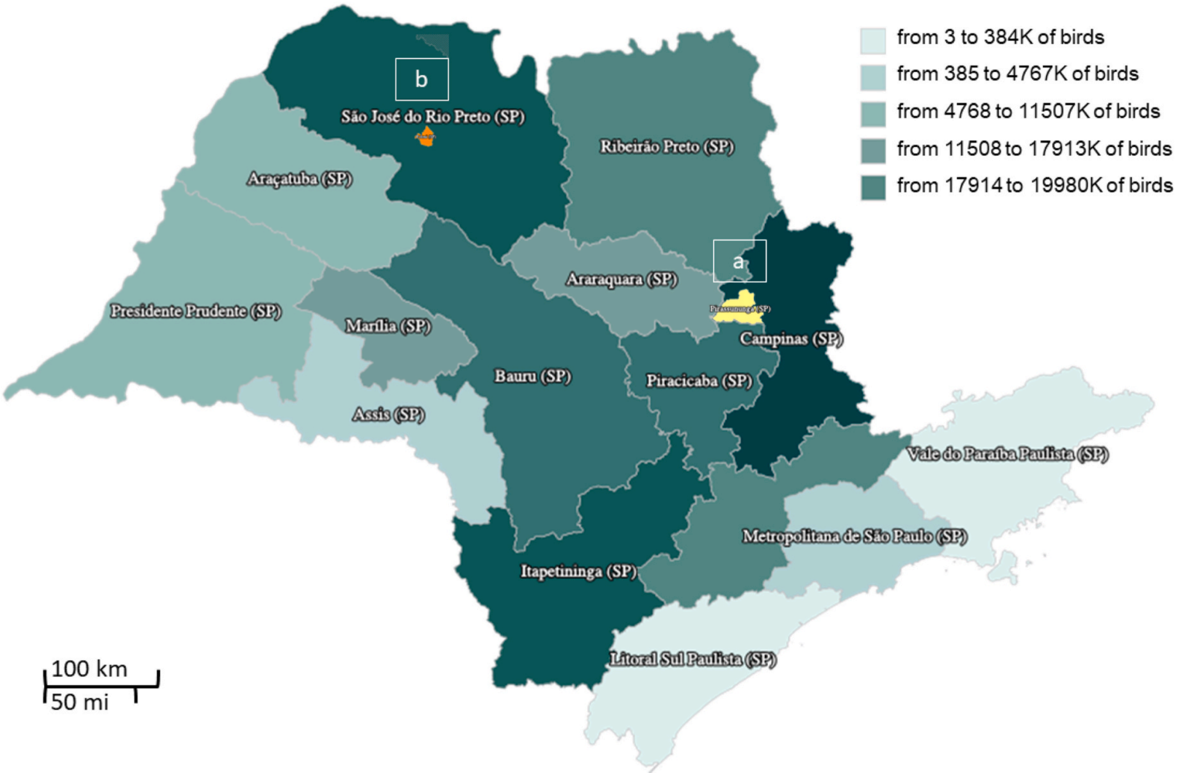

Fig. 1. Location of (a) ***UPrO*** (Pirassununga-SP) and (b) ***UPc*** (Poloni-SP) related to the number of broilers (thousand heads) per establishment according to the mesoregions of the state of São Paulo, Brazil. Note: *UPrO* is the representative production unit for broiler raised in an organic system; and *UPc* is the broiler production unit raised in a conventional system; Source (for data: IBGE; https://sidra.ibge.gov.br/tabela/6943; for map: EstatGeo: https://bityli.com/VdZGu).

Table 1
Main characteristics of the broiler production system in organic (***UPrO***) and conventional (***UPc***) systems.

Housing and accommodation	UPrO	UPc
Produced animals (n)	12,700	25,000
Total area (m^2)	8,459	2,250
Surface covered (m^2)	1,409	2,250
Paddock (m^2)	7,050	–
Cover density (birds/m^2)	9.01	11.11
Paddock density (birds/m^2)	1.80	–
Zootechnical performance		
Flocks/yr (n)	5.5	5.8
Final weight (kg)	2.45	2.55
Slaughter age (days)	43	46
Total consumption (kg/bird)	4.43	4.61
Corn (kg/bird)	2.57	3.00
Soybean meal (kg/bird)	1.37	1.42
Feed conversion (kg:kg)	1.80	1.84
Mortality (%)	3.00	1.38

combined, cannot add up to a sum longer than the emergy source from which they were derived.

For the development of the study, three steps were followed, according to the premises established by Odum (1996) and suggestions by Brown e Ulgiati (2004):

i) Construction of a diagram of the energy flow of the system, defining the energy sources, the system boundaries and the internal components (producers, consumers, stocks, interactions, etc.) (Supplementary material 1; Fig. 2).
ii) Organization of data in an Emergy assessment table; in this table, all resources were described, listed, and later classified according to their origin: natural (*I*) or economic (*F*). The sum of these inputs ($Y = I + F$) demonstrates the value in Emergy produced in the agro-industrial production system (Allegretti et al., 2018) (the calculation memory for GEE emissions and Emergy calculation are presented in the Supplementary material 2); and
iii) Calculations of Emergy indicators and discussion of the results for practical purposes (Table 2). The transformities (*Tr*) of the items listed in the calculation table were obtained from the literature and, when necessary, corrected to the biogeosphere Emergy baseline proposed by Brown et al. (2016) and equal to 12.0E+24 sej/J.

Input values of supplies were calculated from their equivalent monetary transaction value based on Emergy (*Em*\$) per flock and compared to production costs in dollars (USD: R\$ = 1.00:5.00, for June/2021). For this, the *Em*\$ was obtained by dividing the Emergy of a nation by the Emergy/money.

Where: *GEE* are gases that can harm the well-being of humans and animals as well as the zootechnical performance of animals; *heatr* is the heat generated by both the air-conditioning system and the broilers; *R* are local renewable resources; *N* are local non-renewable resources; F_N the non-renewable fraction of purchased inputs; F_R are the renewable fraction of purchased inputs; ratio (*EMR*). The *Em*\$ was obtained from the division of the Emergy collected by each input by the Brazilian estimated *EMR* for 2021 and following data from Giannetti et al. (2013) study (6.08E+11 sej/USD) (Supplementary material 3). From the evolution, process of the Emergy accounting it was possible to incorporate the renewable fraction of the *F* inputs so as to enhance the comprehension on sustainability of systems. The renewable fraction of Emergy of the following items was considered: labor, litter, day-old chicks, corn, and soybean meal, according to Comar e Komori (2007) and Castellini et al. (2006), respectively.

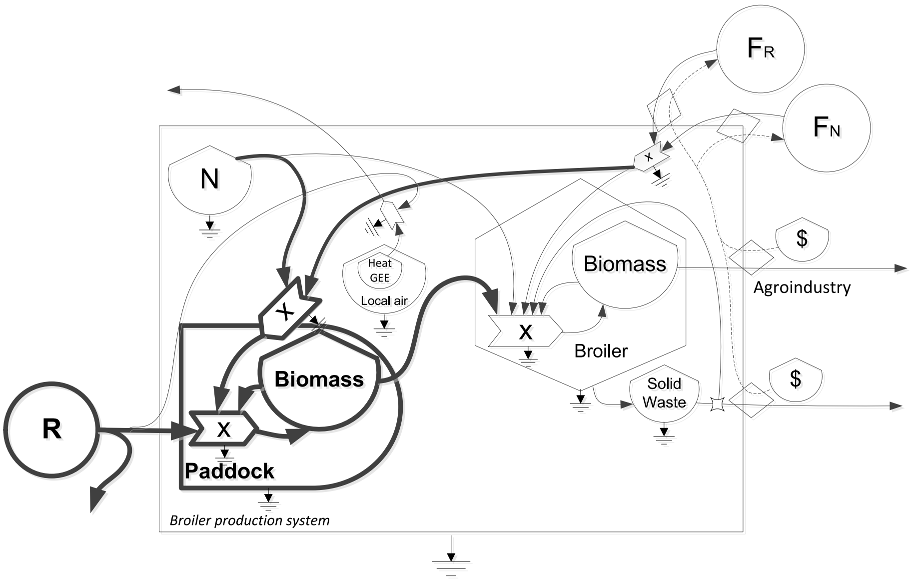

Fig. 2. Emergy flow diagram representing the production of organic (*UPrO*) and conventional (*UPc*) broilers at the farm level. The studied systems present the same technological package for animal feeding, drinker, and air conditioning. Both the organic and conventional broiler production systems showed the same energy sources (Tables 3 and 4). The bullet-shaped symbol in bold (representing paddock plant biomass production) is exclusive to *UPrO*. The outputs were considered the kg of broiler (in live body weight) and the bedding as fertilizer (in kg solid waste). The sale of bedding as fertilizer is optional (switch). It is the producer's decision whether to reuse (feedback) or sell the litter as organic fertilizer for agro-industries. The air conditioning system was used for animal homeothermy (contributing to the heating of the animals in the first two weeks of life and excessive heat in other phases) also to dilute negative externalities in the form of gases (GEE). All the calculation memory for GEE emissions and Emergy calculation are presented in the Supplementary material 2.

Table 2
Description of sustainability indicators on Emergy theory.

Indicators	Equation	Overview	Scope
Solar Trandformity (*Tr*)	$\frac{Y}{Ep}$	Ratio between total Emergy (*Y*) and good or service's energy (*Ep*).	Higher Tr values indicate lower efficiency on using energy When compared to lower Tr vaues.
Emergy Yield Ratio (*EYR*)	$\frac{Y}{F}$	Ratio between total Emergy (*Y*) and non-renewable inputs from economy.	$EYR < 5$ indicate secondary energy sources, $EYR < 2$ indicate products'consumption or transformation processes. Indices close to 1 indicate processes that do not promote meaningful net emergy production and Only transform resources that are made available from previous processes.
Environmental Load Ratio (*ELR*)	$\frac{N+F_N}{R+F_R}$	Ratio between input emergy flows and the renewable and non-renewable inputs	$ELR \sim 2$ suggest low environmental impact. $ELR > 10$ indicate environmental impacy relatively concentrated; and $3 < ELR < 10$ indicate moderate environmental impact.
Emergy Sustainability Index (*ESI*)	$\frac{EYR}{ELR}$	Ratio between net emergy and environmental load ratio of the system.	$ESI < 1$ indicates products or processes that do not possess long-term sustainability; $1 < ESI < 5$ indicates medium-term sustainability; higher values indicate products and processes with longer sustainability.

F: emergy purchased from economy; *R*: Nature's renewable resources *I*: emergy of natural resources; *Y*: total incorporated Emergy; *Ep*: energy of good or service. Source: adapted from Odum, 1996; ULGIATI; BROWN, 1998; BROWN; ULGIATI, 2004. Brown & Ulgiati, 2002

2.3.1. *Emergy ternary diagram*

Emergy ternary diagrams (Giannetti et al., 2006) are expressed as a coordinate system based on an equilateral triangle whose height is equal to its unit. Each height is associated with one of the variables defining a point from a set of three coordinate values, their sum being equivalent to the height of the triangle. These triangular coordinates are inserted from renewable (*R*), non-renewable (*N*) and paid (*F*) resource sources (Fig. 3).

From the ternary diagrams, it is possible to establish limits or identify certain aspects, such as establish the resources lines (*R*, *N*, and *F*) to indicate the constant values to each origin of resources. With its use, it is possible to evaluate and compare two processes concerning the use of resources (Fig. 2-a); establish sustainability lines to indicate the constant values of sustainability ($SI_i = 1$ $SI_j = 2$, $SI_k = 5$ (Brown e Ulgiati, 2002); (Fig. 2-b). Emergy ternary diagrams enable a transparent representation of Emergy accounting results and by enacting as an interface between Emergy researchers and decision-makers (Bonilla et al., 2010). More details about Emergy Ternary Diagram were demonstrated by Giannetti et al. (2006) and Almeida et al. (2007).

3. Results

Fig. 2 presents an overview of chicken production in *UPrO* and *UPc*. The diagram shows the production unit boundaries (farm level) along with the energy sources that drive the process. The time window adopted was one year. Facing diversifying the systems, the symbols in bold (bullet shape representing the production of plant biomass in paddocks) were inserted exclusively for *UPrO*. Against the diagram, both *UPrO* and *UPc* have the same technological package for animal feeding, drinkers, and acclimatizing. On the left side, the sources of local environmental resources are represented. Assets from the economy (i.e. feed, bedding, and labor) are shown at the top of the diagram. On the right side of the diagram, you can see the flow of money (dashed lines) as payment for services and labor, both agro-industry and producer.

Payment for services and labor is made by the producer based on the income obtained from the delivery of live broilers to the agro-industry, at a contractually established price; or even by selling the bedding as a co-product to be used as fertilizer in crops. Agribusiness income is generated from the sale of slaughtered and processed chicken to the market.

The Table 3 and Table 4 describe the Emergy results for *UPrO* and, respectively. Payment for human services represented 10% and 20% of total Emergy (*Y*) for *UPrO* and *UPc*, respectively. For comparisons with other poultry production systems described in the scientific literature, only the indicators without services were considered. Afterward, for the authors, the studies described in the scientific literature do not consider them in the analyses. In addition, depending on the geographic region, there are diversifications in the composition of services (i.e.,

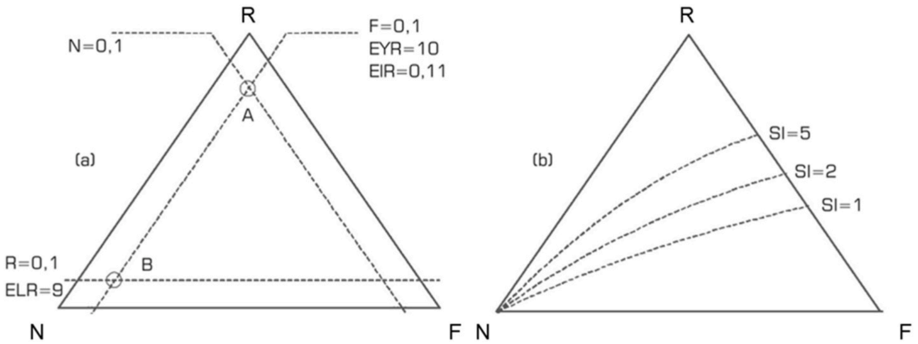

Fig. 3. Representation of (a) two general systems with lines related to the equivale of emergy indices; and (b) the three sustainability lines $\boldsymbol{SI_i} = 1$ $\boldsymbol{SI_j} = 2$, $\boldsymbol{SI_k} = 5$, according to Brown e Ulgiati (2002).

government grants for production) constituting the indices complex to compare to future and existing studies.

Resources *F* were the ones that contributed the most for *Y*, both for *UPrO* and *UPc*. Considering Emergy with services, nutrition (81% and 62%), services (10% and 20%), and facilities (5% and 8%) were the items that most impacted *Y*, for *UPrO* and *UPc*, respectively. Local environmental resources represented <1% of *Y* on both production processes studied. Considering the renewable fraction of the economy's inputs (F_R), the *R*, *N* ,and *F* resources represented 46%, <1%, and 54%; and 15%, <1%, and 85%, for *UPrO* and *UPc*, respectively.

According to scientific literature, ration is the main contributor to *Y* and in specialized poultry production systems. Similar to the results, systems S_1 and S_2, showed more than 50% of *Y* invested in ingredients intended for animal diets (80% and 57%, respectively). Also, systems S_3 and S_4, which deal respectively with organic and conventional broiler production systems, point to the highest fraction of *Y* from ration (85% and 84%, respectively). For the authors, more than 50% of the diets consisted of corn and soybean meal, used as the fundamental sources of energy and protein for the animals. For S_1 and S_2, 69% and 45% of the diet corresponded to the inclusion of corn on the diets, identifying that this is the ingredient that impacts *Y* the most. In recent decades, the intensification of animal production has forced production systems to use grain, with 35% of world production destined for animal feed of commercial interest (Foley et al., 2011). As example, considering the losses and feed use of corn and its products for human nutrition, 34% of the world corn produced in 2019 was allocated to animal feed (FAOSTAT, 2021). In this study, the share of corn and soybean meal corresponded to 70% and 10%; and 28% and 34% of *Y*, for *UPrO* and *UPc* respectively, being the highest difference noticed among the contributions for organic and conventional maize (Fig. 4). In non-specialized systems, feed sources come from vast territories, with little or no external supplementation. With the intensification of production, more broilers were placed in the same area, increasing animal density and competition for food, which was aided by the supply of balanced feed from external sources to the system, exclusively. Appropriately, a greater flow and a greater volume of external energy are necessary to meet the demands of this system. For Lagerberg and Brown (1999), the maintenance of extensive processes in small areas is only possible with considerable Emergy support. In other words, intensification, like the green revolution, made it possible to increase yields per area, but at high energy costs (Lagerberg and Brown, 1999).

3.1. *Production efficiency and level of intensification on poultry systems*

The *Tr* acts as a productive efficiency indicator, as it identifies processes or products that use fewer Emergy units (seJ) to produce a unit of energy in the form of a product (J). For Brown and Cohen (2008), the use of *Tr* as an productive efficiency indicator is possible whereas similar hierarchical levels are related, which justifies its use comparatively. In this sense, the results of *Tr* suggest that *UPc* was more efficient than *UPrO*. Furthermore, the *Tr* calculated with and without services were 1, 05E+06 and 2,60E+05; and 9,41E+05 and 3,28E+05 for *UPrO* and *UPc*, respectively. This fact indicates that for every 1.1 and 1.3 seJ of *Y* used for production, one seJ was assigned to pay for human services for *UPrO* and *UPc*, respectively (Table 5). The *UPrO* results suggest that the system is less efficient than S_3 and S_4 (Castellini et al., 2006); however, more efficient than systems S_1, S_2, and S_6 (Chen et al., 2016; Zhang et al., 2013). Comparing with the S_1 and S_2 results (Zhang et al., 2013), the results point to greater productive efficiency on the *UPrO* and *UPc* systems. Both *UPrO* and *UPc* present a more specialized production for meat, while S_1 and S_2 are systems with dual-purpose poultry (egg and meat production). Thus, the higher efficiency of *UPrO* and *UPc* systems can be compelling both by the degree of specialization of the system and the birds. Since S_1 and S_2 generate energy on producing meat and eggs, it may be inferred that they are less specialized than systems that aim at a single production. Less specialized systems have a lower volume of products converted into energy when compared to more specialized systems (*UPrO* and *UPc*; S_3 and S_4), represented by the low zootechnical indexes presented by S_1 and S_2 (~108 e ~132 eggs/bird.yr; ~200 eggs/bird.yr for birds specialized in egg production (Hy-Line, 2021)). On S_6 system (Guan et al., 2016), despite being a different species of bird (geese) with the same purpose, geese would have a secondary role in meat production, as they are mostly used for pests control of corn crops, therefore it is an integrated system, not a specialized one.

On the other hand, when compared to *UPrO* and *UPc*, S_5 system was more efficient (Cheng et al., 2017). Despite showing less effort for production (*Y*) and lower value of energy(J) produced in outputs, the ratio between *Y* and energy(J) proved to be lower than the ratio presented by *UPrO* and *UPc*. However, considering the production of a system seems to be a crucial indicator for the decision-making among production systems, since the demand for more natural products has grown in recent years. The productive efficiency of the poultry system can be measured from the production intensity, which can be deliberated from *ED*. According to the *ED* results, the systems studied showed a higher degree of intensification than the other systems compared, except for S_4. This system shows 3.9 and 1.7 times higher intensification than *UPrO* and *UPc*, respectively. The difference for the S_4 system can be elucidated by the largest number of birds produced in agreement to its higher density (15.1 versus 9.0 and 11.1 birds/m^2 for S_4 also *UPrO* and *UPc*, respectively). For *UPc*, the difference arises from a lower number of birds housed in the period, which is considered by the authors a strategy of the agro-industry. Toward *UPrO*, the Brazilian organic broilers legislation requires meeting certain aspects. Among them, the lowest animal density is recommended. In Brazil, according to Ordinance No.52, organic broiler production systems must have a density less than or equal to 30 kg of meat/m^2 (~12 birds/m^2 considering a live weight of 2.50kg/bird) (BRASIL, 2021). This implies directly in reducing the number of birds per area over time or increasing the area destined for

Table 3
Emergy table for organic broiler production system (*UPrO*).

Note	Item	Class[n]	Unit	Annual flow (un/yr)	Emergy per unit (seJ/un)	Emergy (E+13) (seJ/yr)	Em$dollar (seJ/$.yr)	Reference
2.1.	Sun[o]	R	J	9,88E+06	1	0.00	0.000	By definition
2.2.	Rain, geopotential[o]	R	J	3,12E+07	1,30E+04	0.04	0.666	[a]
2.3.	Rain, chemical potential[o]	R	J	4,67E+07	9,71E+03	0.05	0.747	[a]
2.5.	Wind, kinetic energy	R	J	7,94E+09	1,28E+03	1.02	16.706	[a]
2.6.	Forced ventilation	R	J	1,00E+11	1,28E+03	0.47	7.705	[a]
2.7.	Groundwater	R	J	4,76E+05	7,67E+04	0.00	0.076	[b]
2.8.	Topsoil losses	N	J	7,14E+08	1,30E+05	9.29	152.719	[a]
2.9.	Soil occupation	N	J	1,02E+08	1,30E+05	1.32	21.736	[a]
2.10.	Wood	F	J	8,44E+04	2,64E+04	0.00	0.004	[a]
2.12.	Bedding	43% R	J	4,14E+11	3,80E+04	1574.77	25900.875	[d]
2.13.	Fuel	F	J	8,93E+09	8,44E+04	125.91	2070.865	[e]
2.14.	Eletric power	F	J	4,35E+10	2,55E+05	1856.93	30541.670	[e]
2.15.	One-day-chicks	16% R	g	6,75E+10	4,64E+05	3134.91	51560.995	[f]
2.16.	Ration	F				149680.56	2461851.336	
	Corn (organic)	58% R	J	2,87E+12	3,45E+05	130351.24	2143934.838	[a]
	Soybean meal (organic)	32% R	J	1,62E+12	1,89E+05	19329.32	317916.498	[g]
2.17.	Paddocks	F	g	1,39E+11	1,92E+04	265.40	4365.139	[h]
2.18.	Mechanical equipments	F	g	2,31E+05	1,82E+09	42.10	692.390	[i]
	Depreciation	F				1.75	28.850	[i]
2.19.	Transport	F				984.56	16193.494	
	Mechanical equipments	F	g	1,24E+06	5,09E+09	629.01	10345.588	[j]
	Labor	5% R	J	1,15E+08	3,12E+04	0.36	5.912	[k]
	Fuel	F	J	2,52E+10	8,44E+04	355.19	5841.994	[e]
2.20.	Labor (manpower)	F				18.53	304.823	
	Technical assistance	5% R	J	1,33E+08	3,12E+04	0.41	6.809	[k]
	Catching	5% R	J	7,14E+07	3,12E+04	0.22	3.666	[k]
	Owner	5% R	J	5,73E+09	3,12E+04	17.89	294.323	[k]
2.21	Buildings	F				9243.43	152030.028	
	Wood	F	g	1,13E+06	6,69E+08	75.39	1240.028	[l]
	Iron	F	g	8,31E+04	2,39E+09	19.84	326.289	[l]
	Sand	F	g	4,51E+05	8,51E+08	38.38	631.232	[l]
	Cement	F	g	1,38E+05	1,57E+09	21.78	358.180	[l]
	Gravel	F	g	4,16E+05	1,28E+09	53.07	872.876	[m]
	Brick	F	g	9,69E+04	1,76E+09	17.08	280.919	[l]
	Tile	F	g	1,82E+06	2,33E+09	422.11	6942.657	[l]
	Fence	F	g	4,17E+07	2,01E+09	8370.32	137669.796	[f]
	Depreciation	F	g	–	–	225.45	3708.049	
2.22.	Services ($ per mˆ2)	17% R	$	3,13E+05	1,29E+12	40480.66	19050.00	[n]
	Labor	17% R	$	2,37E+04	1,29E+12	3058.70	23678.548	
	Technical assistance	17% R	$	3,60E+02	1,29E+12	46.51	360.000	
	Transport	17% R	$	5,15E+03	1,29E+12	665.65	5152.052	
	Eletric power	17% R	$	1,10E+03	1,29E+12	142.12	1099.999	
	Fuel	17% R	$	1,65E+02	1,29E+12	21.32	165.014	
	Heating	17% R	$	1,19E+03	1,29E+12	153.21	1185.800	
	Bedding	17% R	$	6,33E+02	1,29E+12	81.72	632.511	
	Ration	17% R	$	2,17E+05	1,29E+12	28052.55	217125.015	
	One-day-chicks	17% R	$	2,44E+04	1,29E+12	3158.62	24447.500	
	Sanity	17% R	$	2,33E+03	1,29E+12	300.91	2329.050	
	Maintenance	17% R	$	2,21E+03	1,29E+12	285.12	2206.838	
	Rate, insurance, and certifications	17% R	$	3,17E+02	1,29E+12	40.99	317.240	
	Depreciation	17% R	$	7,42E+03	1,29E+12	959.22	7424.286	
	Production factor cost	17% R	$	1,98E+04	1,29E+12	2563.04	19837.935	
	Miscellaneous	17% R	$	7,36E+03	1,29E+12	950.99	7360.591	
	Broiler		g	1,66E+08				
	Bedding as fertilizer		g	2,48E+07				
				No services	With services			
	R		seJ	1,48E+13	1,48E+13			
	N		seJ	1,06E+14	1,06E+14			
	F		seJ	1,67E+18	1,86E+18			
	FR		seJ	8,30E+17	8,62E+17			
	FN		seJ	8,40E+17	9,98E+17			
	Y		seJ/yr	1,67E+18	1,86E+18			
	Tr							
	Broiler		J	9,41E+05	1,05E+06			
	Broiler		kg	1,01E+13	1,12E+13			
	Bedding as fertilizer		J	4,03E+06	4,49E+06			
	Bedding as fertilizer		kg	6,75E+13	7,51E+13			

[n] R: local renewable resources; N: local non-renewable resources; F: external economic resources.

[c] Odum, 1996, (Folio #1).

[a] Giannetti et al., 2013.

[b] Brown, 2000.

[d] Comar and Komori, 2007.

[e] Odum (1996).

[f] Castellini et al., (2006).

[g] Ortega et al. 2004.

[h] Rótolo, 2007.

[i] Bargigli & Ulgiati, 2003.

[j] Brown, 2001 (Folio #3).

[k] Demetrio, 2011.

[l] Brown and Buranakarn (2003).

[m] Pulselli et al., 2008.

[n] Giannetti et al., (2013).

[o] Inputs that were not accounted for to avoid double accounting.

production. In both cases, there is a *ED* contraction by reducing *Y* due to the lower requirement of *F* resources (i.e., feed); or by dividing *Y* into an area significantly larger than that for conventional systems. In addition to determining the animal density in covered areas, another legal aspect contained in the same Ordinance No.52 refers to the availability of 0.4 m^2 of paddock/bird. Access to larger spaces is crucial because it guarantees an acceptable level of animal welfare and higher quality on the final product (Van Poucke et al., 2006; Vanhonacker et al., 2008), in addition to providing healthful status to animals, observed from better indicators of the zootechnical performance of broilers produced with more space (Estevez, 2007). Thus, it can be understood that *UPrO* is a system specialized in the broiler production that, in addition to organic aspects approached via diet, adopts legal practices aimed at animal welfare. In addition, the adoption of such practices did not impair the productive efficiency of the studied system, which could lead to benefits for both animal and human health.

3.2. Sustainability in emergy

Several indicators have been used to assess different aspects of sustainability in Emergy. Among them, Emergy yield and environmental load stand out (Brown and Ulgiati, 1997). Since the production processes are interested in a higher income with the lowest possible environmental load, analyzing the relation between the two indicators becomes of fundamental importance. In this study, *ESI*'s connections are presented in Fig. 5 along with the ternary diagram. According to the results, *UPc* presented the lowest sustainability index ($ESI = 0.19$) while *UPrO* showed the best issues both in comparison to *UPc* and to the other systems ($ESI = 1.97$), excluding S_5. The S_5 system differed from the others conceivably because it had lower *F* entries. Diversified feeding, using residues and byproducts from plant production systems can reduce the *F* participation, since, as observed, the greatest contribution to *Y* in poultry systems with a higher degree of intensification comes from ration.

R: local renewable resources; N: local non-renewable resources; F: paid resources; Points with greater circumference indicate more Emergy used in your processes (*Y*). S_1. Backyard production system(Zhang et al., 2013); S_2. Orchard production system(Zhang et al., 2013); S_3. Organic production system (Castellini et al., 2006); S_4. Conventional production system(Castellini et al., 2006); S_5. Integrated crop-fish-bird system (Cheng et al., 2017); S_6. Integrated corn-geese system(Sha et al., 2015); S_7 Organic chicken production system (*UPrO*); S_8 Conventional chicken production system (*UPc*); ESI_1 = low sustainability, ESI_5 high sustainability.

The possible causes for the worst *UPc* result are correlated to the highest value for *ELR* (6.20 and 1.01, for *UPc* and *UPrO*, respectively). *ELR* is directly related to the dietary ingredients and its renewable fraction (Castellini et al., 2006). For instance, the %*R* for conventional corn was 22%, and 58% for organic corn. Thus, if in one hand, the low rate of renewability of the high energy flows from the ingredients caused *UPc* to have a moderate environmental impact (Brown and Ulgiati, 2004), on the other hand, the high rate of renewability of the high energy flows from the ingredients benefited *UPrO*, causing it to have a low environmental impact.

4. Discussion

The Fig. 6 demonstrates the relationship between *ESI* and the overall productivity (*GP*) of different poultry systems. The *GP* is a measured from the inverse of Emergy/J of the product. The areas formed from the dashed lines indicate the efficiency and sustainability in Emergy processes, indicating the performance that the productive system maintains over time. Thus, the larger the area formed by the lines, the more efficient and sustainable the process will be compared to the others (Bonilla et al., 2010). In this study, along with the production efficiency and sustainability in Emergy, it is proposed to appraise the degree of intensification of the system from *ED*, to represent the productive potential of the process. Hence, points with greater circumference indicate greater density per area that indicate greater production of energy in J in product.

To the preliminary ranking, the largest area may represent the best-ranked system (Bonilla et al., 2010). A first check could point to S_5, *UPrO*, and S_3, respectively, as the most promising systems. However, analyzing the graph, the ranking of systems must meet certain criteria. As an example, the systems to be evaluated must present a certain degree of sustainability in emergy. In other words, $ESI > 1$. For Bonilla et al. (2010), the size of the area per se does not satisfy a sufficient condition and allows to be treated if *ESI* and *GP* are restrained to acceptable values. As it did not meet the $ESI > 1$ criterion, the S_3 system was excluded from the comparisons. The *UPrO* area was 4.5 times greater than the *UPc*. This result indicates that *UPrO* longevity increased by almost two times the *UPrO GP*, while the *UPc* longevity reduced by more than five times the *UPc GP*. However, when compared to S_5, *UPrO* presented an area 18 times smaller, indicating greater *GP* and sustainability for S_5. Agro-industrial systems with a higher degree of intensification are committed to being more productive, presenting a linear design, and requiring greater support from external resources (Almeida et al., 2020). This dependence on external resources makes them less resilient (Agostinho et al., 2019). Agricultural systems with a greater degree of intensification sacrifice part of their sustainability in the name of greater productivity. On the other hand, natural systems tend to present more complex designs, being more resilient (Abel and Stepp, 2003). Thus, as agricultural systems are closer to nature, they will become more sustainable and efficient, as observed for S_5. However, natural systems tend to have lower productivity. According to Odum et al. (1995), systems arranged to be more efficient may do so more slowly, which leads to lower productivity. This fact would make the adoption of this production system unfeasible per se since it would not meet the volume demanded by chicken meat.

Primary axis, $1-4; 6$; *UPrO* and *UPc*; secondary axis, 5; the size of the circumference of the points indicates the *em* power density (*ED*). The larger the girth, the greater the energy density in J per area in the product form;

Areas formed from the dashed lines indicate the efficiency and sustainability in Emergy of the processes. The larger the area formed by the dashed lines, the more efficient and sustainable the process will be.

Table 4
Emergy table for conventional broiler production system (*UPc*).

Note	Item	Class[n]	Unit	Annual flow (un/yr)	Emergy per unit (seJ/un)	Emergy (E+13) (seJ/yr)	Em$dollar (seJ/$.yr)	Reference
2.1.	Sun[o]	R	J	2,63E+06	1	0.00	0.000	By definition
2.2.	Rain, geopotential[o]	R	J	8,29E+06	1,30E+04	0.01	0.177	[a]
2.3.	Rain, chemical potential[o]	R	J	1,24E+07	9,71E+03	0.01	0.199	[a]
2.5.	Wind, kinetic energy	R	J	2,11E+09	1,28E+03	0.27	4.444	[a]
2.6.	Forced ventilation	R	J	1,73E+11	1,28E+03	0.75	12.303	[a]
2.7.	Groundwater	R	J	1,15E+07	7,67E+04	0.11	1.844	[b]
2.8.	Topsoil losses	N	J	0,00E+00	1,30E+05	0.00	0.000	[a]
2.9.	Soil occupation	N	J	6,10E+08	1,30E+05	7.93	130.496	[a]
2.10.	Wood	F	J	1,73E+05	2,64E+04	0.00	0.008	[a]
2.12.	Bedding	43% R	J	4,86E+11	3,80E+04	1845.19	30348.500	[d]
2.13.	Fuel	F	J	1,94E+10	1,41E+05	273.12	4492.139	[e]
2.14.	Eletric power	F	J	6,26E+10	4,27E+05	2672.97	43963.389	[e]
2.15.	One-day-chicks	16% R	g	1,40E+11	4,64E+05	6507.68	107034.277	[f]
2.16.	Ration	F				79317.31	1304561.074	
	Corn (conventional)	22% R	J	7,00E+12	5,10E+04	35689.47	586997.803	[a]
	Soybean meal (conventional)	10% R	J	3,49E+12	1,25E+05	43627.85	717563.271	[g]
2.17.	Paddocks	F	g	0,00E+00	1,92E+04	0.00	0.000	[h]
2.18.	Mechanical equipments	F	g	2,31E+05	1,82E+09	42.10	692.390	[i]
	Depreciation	F				1.75	28.850	[i]
2.19.	Transport	F				1003.96	16512.471	
	Mechanical equipments	F	g	1,24E+06	5,09E+09	629.01	10345.588	[j]
	Labor	5% R	J	1,21E+08	3,12E+04	0.38	6.234	[k]
	Fuel	F	J	2,66E+10	1,41E+05	374.57	6160.648	[e]
2.20.	Labor (manpower)	F				5.64	92.823	
	Technical assistance	5% R	J	1,50E+08	3,12E+04	0.47	7.681	[k]
	Catching	5% R	J	1,51E+08	3,12E+04	0.47	7.738	[k]
	Owner	5% R	J	1,51E+09	3,12E+04	4.70	77.369	[k]
	Registered manpower	5% R	J	5,19E+05	3,12E+04	0.00	0.027	
2.21	Buildings	F				9639.66	158547.024	
	Wood	F	g	1,80E+06	6,69E+08	120.39	1980.173	[l]
	Iron	F	g	1,33E+05	2,39E+09	31.68	521.044	[l]
	Sand	F	g	7,20E+05	8,51E+08	61.29	1008.000	[l]
	Cement	F	g	2,21E+05	1,57E+09	34.78	571.970	[l]
	Gravel	F	g	6,64E+05	1,28E+09	84.75	1393.875	[m]
	Brick	F	g	1,55E+05	1,76E+09	27.27	448.594	[l]
	Tile	F	g	2,90E+06	2,33E+09	674.06	11086.571	[l]
	Fence	F	g	4,17E+07	2,01E+09	8370.32	137669.796	[f]
	Depreciation	F	g	–	–	235.11	3867.001	
2.22.	Services ($ per mˆ2)		$	4,36E+05	1,29E+12	56362.02	26511.563	[n]
	Labor	17% R	$	2,41E+04	1,29E+12	3110.68	24076.450	
	Technical assistance	17% R	$	3,60E+02	1,29E+12	46.51	180.000	
	Transport	17% R	$	1,11E+04	1,29E+12	1434.81	11105.302	
	Eletric power	17% R	$	1,58E+03	1,29E+12	204.58	1583.400	
	Fuel	17% R	$	3,57E+02	1,29E+12	46.16	357.303	
	Heating	17% R	$	2,44E+03	1,29E+12	314.73	2436.000	
	Bedding	17% R	$	1,74E+03	1,29E+12	224.81	1740.000	
	Ration	17% R	$	2,91E+05	1,29E+12	37562.23	290729.319	
	One-day-chicks	17% R	$	5,08E+04	1,29E+12	6556.90	50750.000	
	Sanity	17% R	$	2,53E+03	1,29E+12	326.73	2528.847	
	Maintenance	17% R	$	1,18E+02	1,29E+12	15.29	118.334	
	Rate, insurance, and certifications	17% R	$	2,63E+02	1,29E+12	33.92	262.546	
	Depreciation	17% R	$	1,15E+04	1,29E+12	1481.17	11464.155	
	Production factor cost	17% R	$	2,83E+04	1,29E+12	3652.75	28264.403	
	Miscellaneous	17% R	$	1,05E+04	1,29E+12	1350.76	10449.390	
	Broiler		g	3,65E+08				
	Bedding as fertilizer		g	2,90E+07				
				No services	With services			
	R		seJ	1,02E+13	1,02E+13			
	N		seJ	7,93E+13	7,93E+13			
	F		seJ	1,01E+18	1,28E+18			
	FR		seJ	1,40E+17	1,86E+17			
	FN		seJ	8,73E+17	1,09E+18			
	Y		seJ/yr	1,01E+18	1,28E+18			
	Tr							
	Broiler		J	2,60E+05	3,28E+05			
	Broiler		kg	2,78E+12	3,51E+12			
	Bedding as fertilizer		J	2,09E+06	2,63E+06			
	Bedding as fertilizer		kg	3,49E+13	4,41E+13			

[n] R: local renewable resources; N: local non-renewable resources; F: external economic resources.

[c] Odum, 1996, (Folio #1).

[a] Giannetti et al., 2013.

[b] Brown, 2000.
[d] Comar and Komori, 2007.
[e] Odum (1996).
[f] Castellini et al., (2006).
[g] Ortega et al. 2004.
[h] Rótolo, 2007.
[i] Bargigli & Ulgiati, 2003.
[j] Brown, 2001 (Folio #3).
[k] Demetrio, 2011.
[l] Brown and Buranakarn (2003).
[m] Pulselli et al., 2008.
[n] Giannetti et al., (2013).
[o] Inputs that were not accounted for to avoid double accounting.

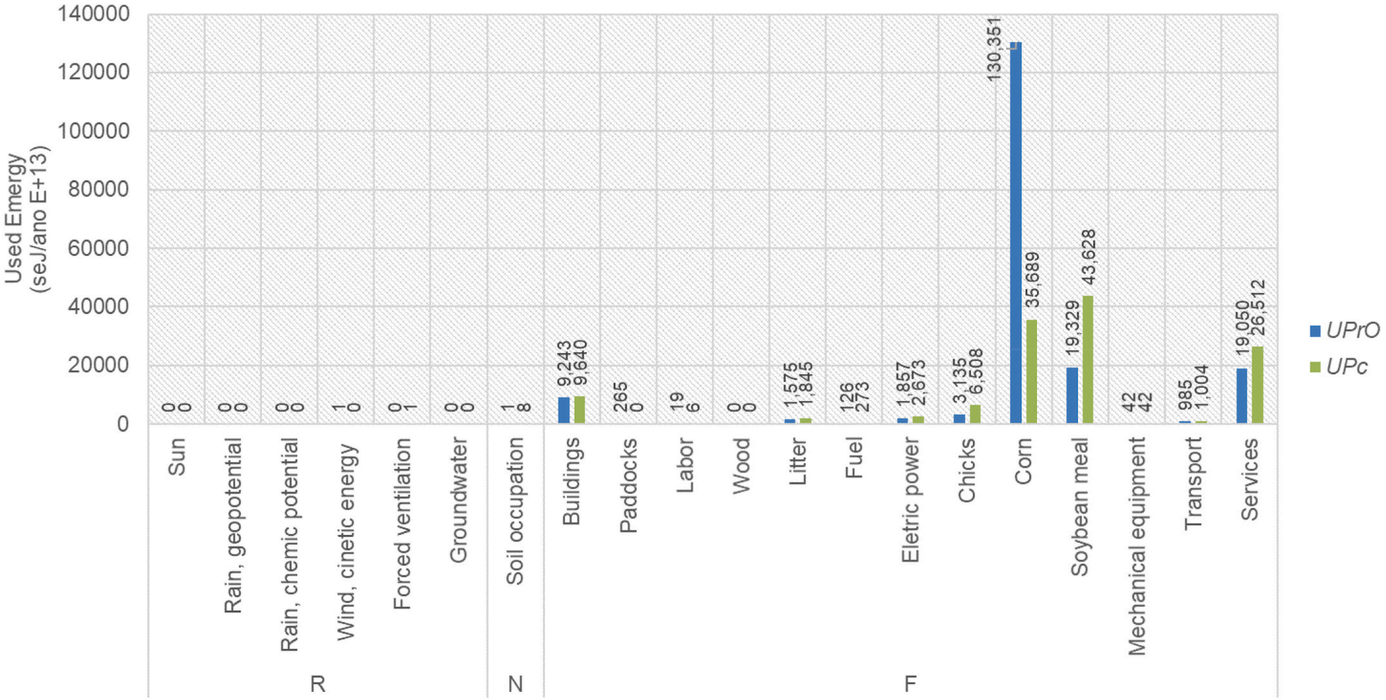

Fig. 4. Emergy signature for organic (*UPrO*) and conventional (*UPc*) broiler production systems. Items were separated according to sources of resources into renewable (*R*), non-renewable (*N*) and imported from the economy (*F*).

Table 5
Comparison of the main Emergy indicators for broilers produced in organic (*UPrO*) and conventional (*UPc*) systems and systems described in the scientific literature.[a]

Index	Equation	*UPrO*		*UPc*		S_1	S_2	S_3 [1]	S_4 [1]	S_5	S_6 [b]
		With	Without	With	Without						
		\$/seJ	\$/seJ	\$/seJ	\$/seJ						
Emergy, ($\times 10^{15}$seJ)	$Y = R + N + F_R + F_N$	1860	1670	1280	1010	10	130	39	420	5	11
Renewability, %	$R\% = F_R + R/Y$	0.46	0.50	0.15	0.14	0.30	0.30	0.29	0.16	0.81	0.37
Transformity, ($\times 10^5$ seJ/J);	$Tr = Y/Ep$	10.48	9.41	2.60	3.28	21.7	15.8	5.79	6.11	2.31	20.0
Em power Density, (seJ/m^2.year $\times$ 10^{14})	$ED = Y/area$	2.20	1.97	5.68	4.50	1.40	0.02	0.04	7.80	0.05	0.08
Environmental Load Ratio, (seJ/seJ)	$ELR = F_N + N/F_R + R$	1.16	1.01	5.89	6.21	2.34	2.28	2.04	5.21	0.23	1.43
Emergy Yield Ratio, (seJ/seJ)	$EYR = Y/F_R + F_N$	1.00	1.99	1.18	1.00	1.43	1.48	1.51	1.19	9.59	1.74
Emergy Sustainability Index, (seJ/seJ)	$ESI = EYR/ELR$	0.86	1.96	0.17	0.19	0.61	0.65	0.74	0.23	41.70	1.22

Where: R are the local renewable resources(seJ/yr); N are local non-renewable resources(seJ/yr); F_R is the renewable fraction of F (seJ/yr); F_N is the non-renewable fraction of F (seJ/yr); Ep is the energy produced in the process as a product(J/yr); S_1. Backyard production system(Zhang et al., 2013); S_2. Orchard production system (Zhang et al., 2013); S_3. Organic production system(Castellini et al., 2006); S_4. Conventional production system(Castellini et al., 2006); S_5. Integrated crop-fish-poultry system(Cheng et al., 2017); S_6. Integrated corn-geese system(Sha et al., 2015).

[a] The value expressed in seJ/flock and converted into seJ/yr by multiplying the total Emergy times the number of flocks/yr for $S_3 = 4.2$ and $S_4 = 5.8$.

[b] Converted from seJ/g to seJ/J, considering the energy value of goose meat (meat, goose, domesticated, meat and skin, cooked, without oil, with salt) at 2,970 kcal/kg according to the Brazilian Composition Table of food (http://www.tbca.net.br/base-dados/composicao_alimentos.php). As it were. $Tr = (1.05E + 16)/((5.60e + 05)/(1e + 03g \text{ to } kg)) * (2.97e + 03 \text{ kcal}/kg) * (4.19e + 03 \text{ kcal to } J)$

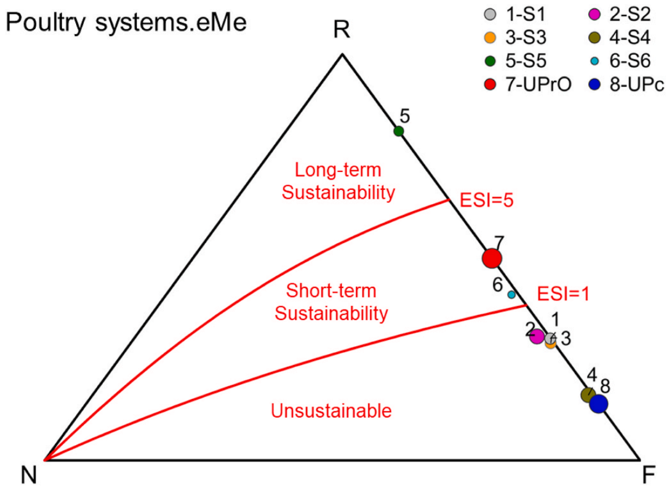

Fig. 5. Ternary diagram representing the Emergy sustainability index of different poultry production systems.

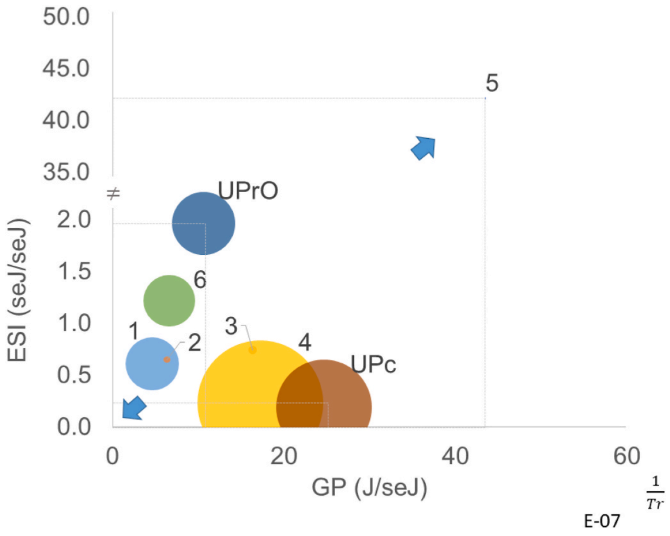

Fig. 6. *ESI* vs. Global productivity chart (energy produced in J/seJ; *Tr*) representing the organic (*UPrO*) and conventional (*UPc*) broiler production system studied and compared to the production systems described in the scientific literature. A rising arrow means good performance. Descending arrow indicates the direction of poor performance.

1.Backyard production system(Zhang et al., 2013); 2.Orchard production system(Zhang et al., 2013); 3.Organic production system(Castellini et al., 2006); 4.Conventional production system(Castellini et al., 2006); 5. Integrated crop-fish-bird system(Cheng et al., 2017); 6.Integrated corn-geese system(Sha et al., 2015); *UPrO*. Organic chicken production system; *UPc*. Conventional chicken production system.

Adopted as a third criterion, the use of *ED* was suggested to measure the productive potential of the system. According to the results, the circumference of *UPrO* is 383 times larger than S_5, indicating that *UPrO* produces more energy(J) than S_5 in the form of product per area. Thus, if one way S_5 presents itself as the most promising system in terms of environmental performance, *UPrO* presents itself as the system with the best productive potential. Hence, to determine the best system to be adopted, the purpose of each production and system must be considered. For the authors, less technological and integrated systems could be organized towards food production focused on supplying for local/regional scope. It is possible that the adoption and encouragement of integrated systems, which combine animal-vegetable production on a small scale, presents itself as a possible way to increase local/regional sustainability (at the city/mesoregion level) by providing greater net Emergy in the form of product for the region. From an Emergy point of view, encouraging production diversification, integrating animal-vegetable production could: (i) take advantage of feedbacks between systems (i.e., poultry litter for vegetable fertilization); and (ii) increase the capture and yield of *R* resources. In addition, fewer technological systems are well-known bring food security and income to smallholders (Figueiredo et al., 2015; Silva Junior et al., 2019). In general, public policies must be directed both to grant the implementation of systems that integrate animal-vegetable production, as well as to technological transfer and implementation. Regarding the grant, Brazil has a long successful experience with funding lines directed to small-producer. Among them is the BNDES's Rural Credit Program (Pronaf; Brazilian Development Bank). For example, the Pronaf Agroecologia is a funding line for the implementation and maintenance costs of agroecological or organic production systems to be directed for small producers (BNDES, 2022). Regarding the technological transfer, the Brazilian Agricultural Research Corporation (Embrapa) is a governmental enterprise responsible for technological innovation development focused on generating knowledge and technology for Brazilian agriculture. One example of technological innovation is the Sistema Integrado para Produção de Alimentos (Embrapa, 2016). The Sistema Integrado para Produção de Alimentos is an example of an integrated animal-vegetable production system for urban and rural small-areas ($\geq$ 100 m^2). This system seeks for low implementation and maintenance costs, food security and production flexibility according to the consumers' demand. Thus, Pronaf Agroecologia could subsidize the Sistema Integrado para Produção de Alimentos implementation, being the excess used to supply the local/regional consumers. In contrast, products from systems with higher degree of intensification, as well as *UPrO*, could be destined mostly for foreign trade. Using models proposed by Odum (1996), Luiz et al. (2021) aimed to estimate the Emergy exchange ratio between nations and found that Brazil has benefited from some of its main trading partners in the exchange ratio for chicken meat over the previous 18 years. In other words, Brazil received more energy from money than it supplied in the form of a product.

A third observation suggests the intermediate position that *UPrO* occupies among the studied systems. According to the results, it is possible to infer that *UPrO* is average among the most efficient systems in energy(J) production in the form of product (S_4 and *UPc*) and the most promising in terms of environmental performance (S_5). Since the highest theoretical values for *ESI* ($ESI = \infty$) can only be achieved in mature and untouched ecosystems, it should be kept in mind that there is a limit to the best environmental performance in processes managed by human actions. As observed, the largest fraction of *Y* in poultry systems with the highest degree of intensification comes from the diet. Since sustainability can be a relationship between yield and environmental burden, and this yield comes from less concentrated sources of energy, reducing environmental burden may be the best choice to increase sustainability. In this sense, changing the composition of diets and seeking ingredients with higher %*R*, may be the best option to reduce the environmental burden. According to Castellini et al. (2006), ingredients intended for diets for chickens and produced organically have a higher *R*%, since inputs of chemical fertilizers or pesticides are not used in production. For the authors, organic ingredients presented *R*% around 60% while i.e. conventional corn presented *R*% of 22%. In this study, knowing that corn was one of the main contributors to total Emergy, considering the renewable fraction of organic corn allowed for a higher *R*% of organic chicken when compared to conventional chicken (50% vs. 14%, respectively). However, knowing the limitations of *R*% in organic ingredients and their inclusion in diets, it is possible to suggest that the best environmental performance presented by *UPrO* is at the limit for systems specialized in the production of broilers with a high degree of intensification.

In summary, the paths to sustainability in processes under human control pass through careful decisions and the choice of multi-criteria standards. These decisions must include several factors that consider (i) the environmental burden generated by the procedure, (ii) its yield and, (iii) its renewability (Brown and Ulgiati, 1997). For the authors, further measuring and comparing the intensity of the process and production efficiency can be interesting for decision-making in choosing better agricultural proceedings. The integrated analysis from the use of tools that aim to consider not only the yield and the environmental load (*ESI*), but also the productive efficiency from the global productivity and the degree of intensity of the process (i.e., *Tr* and *ED*), can culminate in an evaluation that seeks the best option among agricultural processes that meets both environmental criteria and the demand for a particular product. *ED* is the Emergy indicator of choice as it is used to measure production intensity per area (Brown and Ulgiati, 2004). From the *ED* it is possible to suggest agricultural processes with greater production of energy in the form of food. On the other hand, the increase in production should not imply an increase in the environmental impacts generated by the process. In this sense, it is necessary to integrate and evaluate the intensification of production to criteria that assess sustainability. In recent years, the term “sustainable intensification” has gained prominence in the scientific literature (Ayantunde et al., 2019; Cortner et al., 2019). For Garnett et al. (2013), a sustainable intensification is an approach that makes it possible to increase food production with low environmental impact; and that does not limit the ability of current and future generations to produce food. In this sense, the tools presented in this study are suggested to evaluate the sustainable intensification of agricultural processes.

4.1. *Conclusion*

The main conclusions are listed below:

a) From the combination of intensity indicators (*ED*), efficiency (*Tr*) yield and environmental load (*ESI*), the Emergy analysis can generate tools that allow the study of systems that propose paths for “sustainable intensification”;
b) According to the primary ranking of the systems made possible by the graphic tools, *UPrO* presented an intermediate position to the other systems, demonstrating good indicators of productive efficiency and environmental performance.
c) The *UPrO* showed better environmental performance than *UPc* while *UPc* showed better productive efficiency. The *ESI* results indicated that *UPrO* is sustainable in the short term, while *UPc* is unsustainable.
d) Corn and soybean meal were the inputs that most contributed to the total Emergy for both systems. Since the yield comes from less concentrated sources of energy, the decision-making should be focused on to improve the environmental performance of the commercial broiler production systems being directed towards the reduction of the environmental load, from the use of ingredients with higher *R*%, i.e. organic corn and soybean feed usage;
e) Commercial broiler production systems are dependent of corn and soybean meal. According to the scientific literature, the renewability of organic ingredients is limited around 60%. Considering that organic broiler systems use organic ingredients, it is possible to suggest that the environmental performance presented by *UPrO* is at the limit for commercial broiler production systems with a high degree of intensification. Therefore, it is necessary to develop studies that propose the Emergy analysis integrating the production of organic corn and soybean meal used in commercial chicken feed.

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CRediT authorship contribution statement

Rafael Araújo Nacimento: Methodology, Validation, Investigation, Writing – original draft. **Danny Alexander Rojas Moreno:** Methodology, Writing – original draft. **Vitória Toffolo Luiz:** Methodology, Writing – original draft. **Taynara Freitas Avelar de Almeida:** Methodology, Writing – original draft. **Vanessa Theodoro Rezende:** Methodology, Writing – original draft. **Joice Maria Bazerla Andreta:** Investigation. **Cecília Mitie Ifuki Mendes:** Investigation. **Biagio Fernando Giannetti:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision. **Augusto Hauber Gameiro:** Conceptualization, Writing – original draft, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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