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Economic and Environmental Assessment Using Emergy of Sheep Production in Brazil

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Abstract: This study aimed to evaluate the economic and environmental performance of a Brazilian sheep production system (in the São José do Rio Preto (SJRP) region). The cost of production and the emergy indicators were calculated, and compared with other scientific results. The study was divided into three stages: (i) construction of the conceptual model; (ii) transformation of all resources and stocks by unit emergy value; and (iii) analysis of emergy indices. For emergy analysis, imported purchased inputs (P) represented 59.84% of all emergy, in which soy and corn contributed 16.14% and 11.38%, respectively. These inputs also contributed significantly to the economic cost of production as 14.63% and 12.55% of the total cost, respectively. Compared to other production systems, the SJRP system presented a lower emergy production rate and a higher environmental load rate, reducing the emergy sustainability index. In addition, it had the highest level of investment in emergy, suggesting that its sustainability is inferior to other referenced production systems. However, the SJRP system had the lowest emergy exchange ratio, indicating that this system is the closest to a fair price. In conclusion, the system must be reconsidered to become more sustainable; mainly with regard to the confinement of lambs that consume large amounts of concentrate (corn and soybean) from outside the system.

Keywords: emergy accounting; farm management; production costs; sheep production

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1. Introduction

After the Brundtland Report [1] stated that sustainable development must meet the needs of the present without compromising the ability of future generations to meet their own needs, efforts have been made to align animal production systems with the sustainable development model. Regarding sustainable agriculture and food production, according to the Sustainable Development Goals, efforts must be guided to guarantee the use of more resilient agricultural practices in food production systems, helping in the maintenance of the ecosystems and impacting the progressive regeneration of soil and earth quality [2]. In this sense, for livestock, sustainability is one of the challenges for decision-makers since it is necessary to manage the activity by integrating the multiple economic, social, and environmental objectives at the production unit level. Thus, the sustainability of production processes and systems does not have a single, universally valid definition, and there are several contrasting approaches related to resource availability and carrying capacity, resource use efficiency, equity in resource participation, intergenerational equity, environmental dynamics, and constraints [3].

In the allocation of resources in animal production, guided by the concept of sustainability, natural capital is considered irreplaceable by the production of consumer goods and the supply of utility [4]. In this sense, natural and human-made (human, physical, financial, and social) capital stocks complement the search for sustainability. Smith et al. [5] argued that the emerging and expanded concept of capital (natural, human, and produced) represents the most appropriate conceptual framework for an information system aimed at sustainable development. This is due to the existence of a well-developed set of ideas regarding the concept of the five capitals (financial, physical, human, natural, and social) that provide clear guidelines on what such an information system should measure [6]. To this end, the identification and measurement of the capital goods (or assets) that provide the flow of services needed for development is of paramount importance. These fundamentals justify the accounting of natural resources in the economic analysis of livestock.

A relevant sustainability assessment of decision-making in the productive unit (farm) should use indicators integrating information on economic and environmental efficiency with technical indexes that measure the system's performance. In this way, it is possible to answer the following questions: Is the current state of the livestock system sustainable? How sustainable is it? What characterizes its sustainability or lack thereof? Thus, this study proposes the integration of economic and ecological indicators based on two methods: emergy assessment (proposed by Odum [7]) and production costs analysis (according to neoclassical economics theories), to evaluate the sustainability of livestock production systems. A representative Brazilian sheep production system was used as the object of this evaluation. Studies that have aimed to evaluate the production cost in lamb production systems are described in the scientific literature [8,9]. However, there are few studies that have aimed to evaluate the sustainability of lamb production systems using emergy indicators [10]. In addition, to our knowledge, there are no studies that have aimed to evaluate the sustainability of lamb production systems integrating emergy and economic indicators.

2. Materials and Methods

2.1. Systems Description and Primary Data Gathering

Different types of sheep and lamb production systems co-exist in São Paulo, each featuring different productivity indexes, handling methods, intensity of labor use, and use of emergy, each obtaining different results [11]. According to the Brazilian Institute of Geography and Statistics [12], the region of São José do Rio Preto (SJRP) is one of 11 regions in the state of São Paulo, in southeastern Brazil, representing 22% of sheep establishments in the state (1418 sheep farms), and is recognized as one of the most critical regions for sheep production (Figure 1). The average altitude in this region is around 500 m. It has a tropical climate, with a mean annual temperature of 24 °C and total annual precipitation of 1383 mm [13].

Figure 1. Geographical location of the region of São José do Rio Preto, São Paulo state, Brazil.

The data collection and characterization of the representative productive system of this region are based on previous research carried out by Raineri et al. [9] and adopted by the lamb production cost index (Índice de Custo de Produção do Cordeiro Paulista (ICPC), 2019), developed by the Laboratory of Socioeconomic Analysis and Animal Science (LAE) of the University of São Paulo (USP) (Supplementary Materials S1).

2.2. Economic Evaluation

The data collection, the production yield, and the characterization of the representative productive system are based on an analysis by Raineri et al. [9], and were obtained using the panel method, as used by the author. The sheep production system on the representative farm in the SJRP region was analyzed for one year, according to the calculation model developed by Raineri et al. [8]. The cost allocation was based on economic theory and distributed into the following categories: (i) variable costs (feeding and veterinary expenses); (ii) fixed operating costs (labor, electrical energy, fuel, depreciation of technical equipment, installations, rams, maintenance of facilities, equipment, and pasture); and (iii) total cost (solely representing the cost of lambs produced). The input prices required for the system's operation were obtained by the lamb production cost index (Índice de Custo de Produção do Cordeiro Paulista (ICPC), LAE [14]), which calculates monthly the cost of lamb production in the state of São Paulo.

2.3. Emergy Assessment

The emergy methodology presented by Odum [7] recognizes that over a long period of evolution, the biosphere has accumulated natural capital stocks in the form of forest and marine biomass, oil, shale, coal, and phosphate, among others, which have been, and continue to be, consumed by society at higher rates than that of the capacity to replenish these resources in a given period, therefore in a non-renewable way.

Sustainable development requires that production systems be adjusted to the stocks of non-renewable natural resources compatible with the needs and well-being of current and future human generations. Emergy is the available energy of a specific type of stock previously used to produce a resource, service, or product. It is, therefore, the "memory" of energy used. Its unit is the solar emjoule [7].

The emergy assessment method allows alternative livestock systems to be compared in terms of sustainable development. According to Vieira et al. [15] and Agostinho et al. [16], emergy can be used for sustainability assessment as it allows for the use of different resources (natural and non-natural) to be compared, which is essential in the assessment of technologies in terms of resource consumption. Emergy considers that the dependence on renewable resources determines the sustainability of a system, and to assess this aspect of sustainability, the renewable fraction of the total emergy used by the system is estimated [17]. Emergy uses broad spatial and temporal scales, considering natural and economic resources in the different forms of energy, materials, human labor, and economic services on a shared basis, offering more significant potential for exploring the interaction between the environment and the economy [18].

To calculate the emergy, there are three steps that must be followed, according to the methodology proposed by Odum [7]: (i) designing an energy flow diagram of the system defining the main inputs and outputs used and the boundaries of the system; (ii) the organization and building of emergy flow calculation tables; (iii) the calculation of emergy indices, followed by a discussion of the results for practical purposes. For our work, we add an economic analysis to the first step, which helps to define the boundaries of the system.

In the first step, the symbols proposed by Odum were considered to differentiate the types of sources and the interactions between the components of the system (source, internal stocks, producers, and consumers). See Supplementary Materials S2 for all the symbols used. Applying the principles of systems ecology [7], the local resources from the environment were located on the left side of the diagram, and the inputs from economics (materials and services) were located at the top of the diagram. Regarding the system outputs, the products generated by the system were located on the right side of the diagram, and the energy sink or entropy lost to the lake in the production process was in the lower part (Figure 2). The economic analysis helped to identify and define all the resources used in the system.

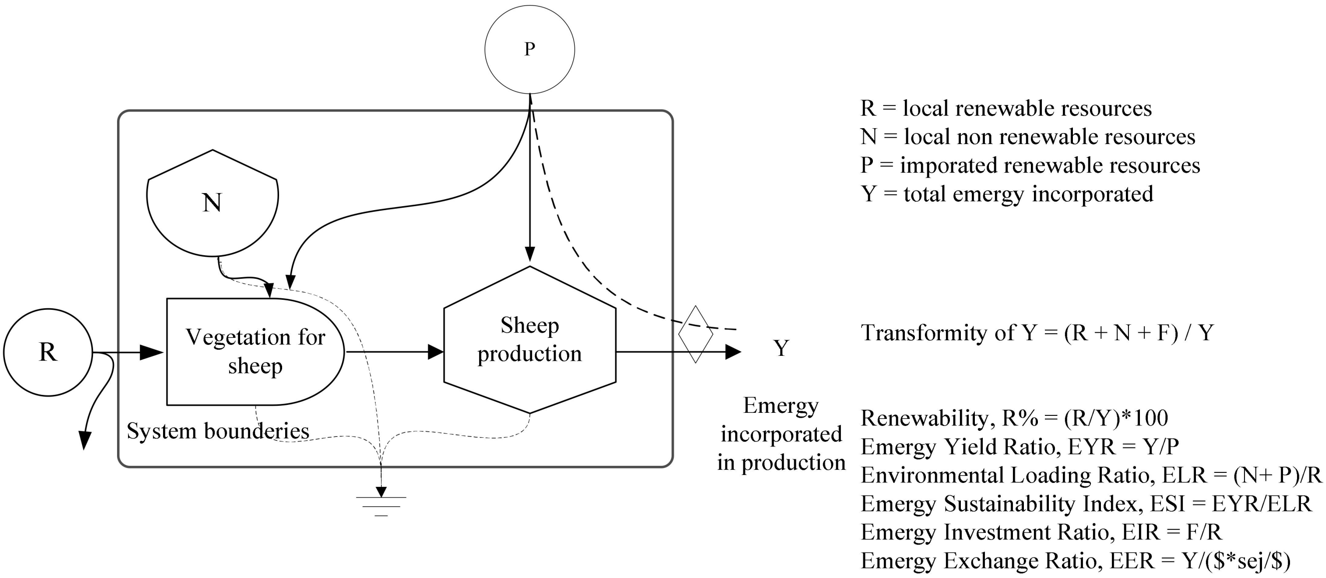

Figure 2. Generic energy diagram of sheep farming systems. The diagram shows the aggregate emergy flows of the environment (N and R), aggregate emergy flows from the economy (P), with the respective renewable and non-renewable fractions, and the flow of total emergy used (Y = R + N + P) incorporated in the product. This illustration contains the symbols, nomenclature, and indices usually considered in the emergy theory [3].

The second step was to build the emergy table, which converted all the input and output flows represented in the flow diagram into accounting lines. Each flow was expressed in grams (g or kg) for mass, joules (J) for energy, or money ($), according to its case. Next was multiplying the amount of input (mass, energy, or money) by its corresponding unit emergy value (UEV), transforming the flow into solar emergy per energy (seJ/J, transformity), emergy per mass (seJ/g, specific emergy), and calculating the emDollar as described by Odum [7], emergy per emergy/dollar ratio (seJ/Em$Dollar). The organization of the energy flow assessment table and all the calculations are explained in Supplementary Materials S2. The emergy table manages to quantify all contributions from local renewable sources (R), local non-renewable sources (N), and imported non-renewable sources (P). The imported renewable sources (P) also include labor and services (L&S). The total emergy flow (Y) is understood as the energy flow used by the system.

The last step was to estimate the emergy indices according to Odum [7]. These indicators provide information on the relationships between the types of resources used in the system. The indexes used in this work were: transformity (Tr), emergy yield ratio (EYR), environmental loading ratio (ELR), emergy sustainability index (ESI), emergy investment ratio (EIR), %Renewability (%Ren), and emergy exchange ratio (EER). The meaning of each of these indices is explained in more detail in Supplementary Materials S2.

2.4. Emergy Ternary Diagram

An emergy ternary diagram is a graphical tool that produces a triangular plot of three variable resources with a constant sum: renewable (R), non-renewable (N) and imported from the economy (P) flows. These flows are represented by an equilateral triangle in which each corner represents a flow, and each side represents a binary system. Thus, each point shown in the triangle represents an R, N, and F flow combination. In this way, the relative proportions of the elements are represented by the lengths of the perpendicular lines from a given point to the side of the triangle opposite to the considered vertex. In addition, the "composition" of any point plotted on a ternary diagram can be determined by reading from zero along the basal line (axis) at the bottom of the diagram to 100% at the vertex of the triangle. The lines related to equi-values of environmental indices enable the verification of the emergy indices EYR, ELR, EIR, and ESI. For this study, only the ESI graphical determination is illustrated [19–21].

3. Results

3.1. Description of SJRP Sheep System

The sheep production systems in the SJRP region are characterized as having relatively large commercial herds (approximately 300 ewes in reproduction per flock); these sheep farming systems are managed mainly for the commercial production of meat. This type of sheep production has specialized pasture systems with Tifton 85 (*Cynodon* spp. cv. Tifton 85), employing the pasture rotation technique and applying fertilizer and limestone. The representative farm in this region presented stocking rates of 24 ewes per hectare (more than two animal-unity/ha). The reproductive management of these systems is of intermediate intensity, as they have breeding seasons of up to three lambs per ewe every two years. As previously mentioned, most of the systems located in the studied region have semi-intensive management, and in this system, it is expected that ewes are kept in pastures and lambs are confined (~60 days) from birth to sale (semi-confined system). The ewes that remain under grazing conditions receive supplementary feeding at the late gestation and early lactation stages. This supplementation may be of grain and sugar cane silage; however, during the dry season, the ewes are only supplemented with mineral salt. The lambs are in a feedlot and receive soybean meal, corn, sugar cane silage, and mineral salt as supplementation.

Regarding animal health, vaccines and anthelminthics are used against clostridium and nematode parasitism, respectively. The facilities and equipment include housing adapted for this activity, a 75 hp tractor with a 4-wheel trailer, a forage harvester, and a weighing machine. For the depreciation of the livestock component, only ewes and rams were considered (see Supplementary Materials S1 for more specific information about the representative farm).

3.2. Production Costs of the System

Feed (62%) is the most expensive component of the total costs, of which 20% represents concentrated lamb feed. Operational fixed costs that represent energy and fuel, depreciation, and maintenance and preservation represent 15% of the total costs, and labor and services are 22% of the total cost (Supplementary Materials S1).

3.3. Emergy System Diagram of Sheep Production

The emergy system diagram of the representative sheep production system in the region of São Jose do Rio Preto is presented in the Figure 3.

The flows of the main inputs that are purchased in the market and that compose the production cost structure are allocated on the right and upper edges of the diagram. These flows occur in a financial feedback cycle associated with the sale of products, which in the case of the farm studied, refers to the lambs, culled animals, and breeding animals that are replaced every three years. The financial flows of product sales and the purchase of inputs form the financial capital stock of the production unit (farm). The production cost structure also considers the use of internal stocks, during the economic evaluation period, including the infrastructure (constructions, machinery, and equipment and their respective depreciation), animals (breeders), pastureland areas that form the physical capital, and human capital formed by permanent labor (salaried, fixed) and day labor (from outside the system). The energy flows from the environment's sources (sun, wind, rain, and stream water) that form the natural capital are allocated on the left side of the diagram. In general, the environment's energy sources are free of charge (in the case of stream water, they may be subject to payment for the use of the water, according to the rules of the river basin). At the bottom of the diagram, the energy output flow due to the system's entropy is represented (energy degradation that will not produce work). The conceptual model identifies all the relationships between the resources obtained from outside and inside the system (represented by the rectangle), and the internal relationships. In the diagram, it is possible to identify two self-catalytic feedback cycles: recycling animal waste to the soil and cycling pasture to the soil, which are essential for the system's sustainability.

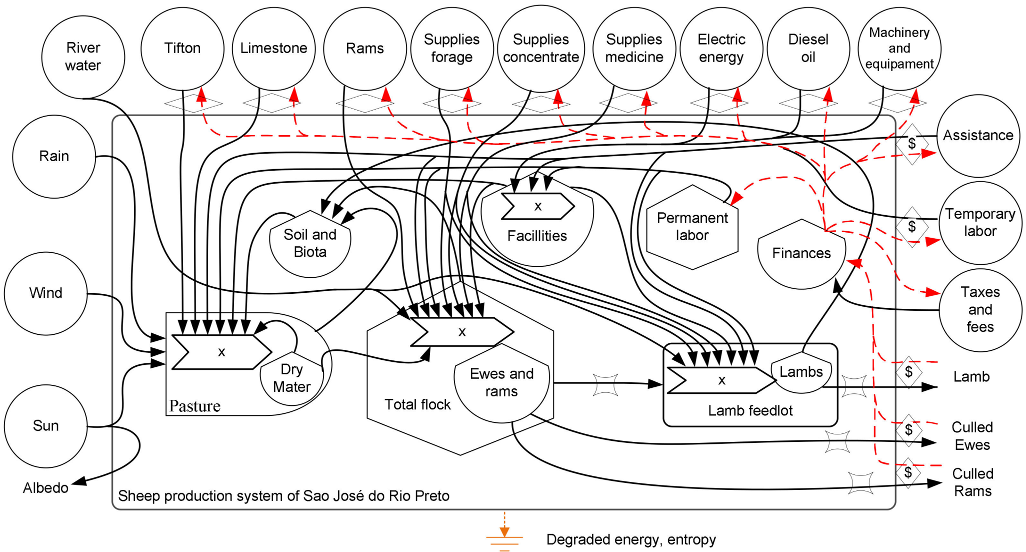

Figure 3. Emergy system diagram showing the interrelation between renewable (R) and non-renewable (N) flows and inputs to the human economy (P and S) in the region of São José do Rio Preto, SP, Brazil.

3.4. Emergy Tables and Indicators

In emergy terms, the purchased inputs (P) represent 60% of the whole emergy. Corn (11%) and soyabean meal (15%) used in the feed program of feedlot lambs appeared as the most important inputs. Renewable inputs (R) and non-renewable inputs corresponded to 18% of the total emergy, each. Services corresponded to 22% of the whole emergy. The energy and emergy flows, units, transformities, Em$Dollar, and percentage, as well as the memory calculation for each item of lamb production in the system, are presented in Supplementary Materials S2.

The estimated emergy indexes for the SJRP sheep production system are presented in Table 1, with and without the service contribution emergy. The UEVs of sheep farming in SJRP were calculated in terms of the total amount of emergy needs to produce one unit of exergy (transformity, Tr) in the form of lamb meat expressed in sej.year. The value of the UEVs found for the live lamb production system was 4.39×10^4 seJ/J with labor and services, and 3.43×10^4 seJ/J without labor and services.

Table 1. Emergy indices for the sheep production system in São José do Rio Preto.

Emergy Indices [1]	**Modified Expression**	**SJRP**		**Units**
		Services	**No Services**	
UEV	UEV = Y/Ep	4.39×10^4	3.43×10^4	sej/J
EYR	Y/F	1.68	1.78	sej/sej
ELR	(N + F)/R	1.49	1.28	sej/sej
ESI	EYR/ELR	1.13	1.39	sej/sej
%Ren	(R/Y) × 100	40	44	%
EIR	F/I	4.49	3.28	sej/sej
EER	Y/($ * seJ/$)	0.09	0.07	sej/sej

[1] UEV: unit emergy value (transformity); EYR: emergy yield ratio (self-sufficiency); ELR: environmental loading ratio (environmental stress); ESI: emergy sustainability index (sustainability); %Ren: percentage of renewability (renewability); EIR: emergy investment ratio (dependency); EER: energy exchange ratio (delivered emergy).

The studied sheep production system, when considering or excluding services, presented an EYR, ELR, and ESI of 1.68 or 1.78, 1.49 or 1.28, and 1.13 or 1.39, respectively. The estimated value for renewability was, respectively, 40% or 44%, when accounting or not for labor and services. The estimates for the EIR and EER, considering services or not, were 4.49 and 3.28, and 0.09 and 0.07, respectively.

4. Discussion

The emergy methodology allowed for the calculation of the emergy indexes as proposed by Odum [7]. The studied lamb production system presented ELR = 1.49, indicating that it produces low long-term impacts on the environment. In other words, the SJRP system showed environmental degradation. According to Brown and Ulgiati [22], ELR < 2 indicates relatively low environmental impacts, or processes that can use large areas of a local environment to “dilute impacts”. On the other hand, the SJRP lamb production system showed activity with a low net emergy production (EYR = 1.68). According to Brown and Ulgiati [23], activities with an EYR ranging from 1 to 2 produce a small amount of net energy. Systems with an EYR of 2 to 5 contribute moderately to the growth of society. Transformity processes with an emergy yield greater than 5 are production systems that present high net energy and contribute significantly to economic growth. Thus, despite a low environmental cost, the SJRP system is very dependent on the resources of the economy and presents a poor capacity to utilize the local renewable resources. This complements our calculations of EIR = 4.49, highlighting the dependence on external flows of the economy.

Compared to Rodríguez-Ortega et al. [10], the SJRP system showed similar proportions in the behavior of emergy flows for the partially-integrated mixed sheep-arable crops (SAC) system, integrating pastures and crops. Among the systems analyzed by the authors, the SAC system showed fewer days of grazing and a greater inclusion of other feed inputs, such as grains, silage and oilseeds, which led this system to present a greater dependence (EIR = 1.44) on inputs from the economic system. However, the level of dependence of the SJPR system (EIR = 4.49) on the economic system (P) was three times higher than that of the SAC system, because finishing lambs in feedlots forces the system to acquire a greater quantity of feed inputs from the market (Table 2).

Table 2. Comparison between the emergy indicators found for sheep farming in São José do Rio Preto and results from the literature.

Farming Systems	UEV [a]	EYR [a]	ELR [a]	ESI [a]	%Ren [a]	EIR [a]	EER [a]	References
SJRP [1]	3.43×10^4	1.78	1.28	1.39	34.18%	3.28	0.07	Research data
SJRP [2]	4.39×10^4	1.68	1.49	1.13	40.22%	4.49	0.09	Research data
SMP [3]	1.70×10^7	2.60	0.53	4.92	58.40%	0.62	11.78	Rodríguez-Ortega et al., 2017
SPC [4]	8.54×10^6	2.16	0.95	2.27	45.20%	0.86	10.68	
SAC [5]	4.79×10^5	1.69	3.22	0.53	19.30%	1.44	5.65	
BCSS [6]	4.39×10^{15}	4.80	0.30	13.9	75.00%	0.40	-	Salas et al., 2017
MACSS [7]	1.62×10^{15}	4.30	0.40	10.1	70.00%	0.30	-	Salas et al., 2017
BACSS [8]	1.45×10^{15}	5.80	0.30	21.5	79.00%	0.20	-	Salas et al., 2017
GC [9]	-	3.73	0.55	6.80	65.00%	0.37	-	Rótolo et al., 2007

[1] SJRP: São José do Rio Preto not considering the emergy of services; [2] SJRP: São José do Rio Preto considering the emergy of services; [3] SMP: specialized sheep and mountain pasture in Spain; [4] SPC: fully integrated mixed sheep and permanent crops in Spain; [5] SAC: partially integrated mixed sheep and arable in Spain; [6] BCSS: Brazilian cattle and sheep system; [7] MACSS: medium farmer cattle and sheep system in Argentina; [8] BACSS: big farmer cattle and sheep system in Argentina; [9] GC: grazing cattle in Argentina. [a] UEV: transformity (sej/J); EYR: emergy yield ratio (self-sufficiency); ELR: environmental loading ratio (environmental stress); ESI: emergy sustainability index (sustainability); %Ren: percentage of renewability (renewability); EIR: emergy investment ratio (dependency); EER: energy exchange ratio (delivered emergy).

On the other hand, it can be observed that the systems that presented a greater renewable emergy flow were the ones with a lower level of dependence on the economic resources. This lower level of dependence on F inputs leads the systems to present lower levels of environmental load (ELR) and thus greater environmental sustainability (ESI) (Figure 4). The ESI assesses the relationship between the economy and the environmental load of the system. This indicator suggests a higher level of sustainability for systems that use the environment's resources more rationally [24].

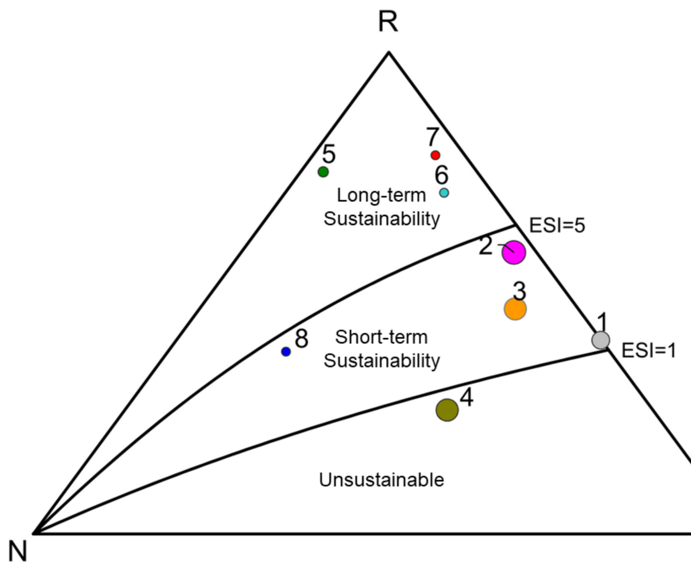

Figure 4. Ternary diagram representing the sustainability of sheep production systems, considering: (1) a representative lamb production system from the Brazilian region of São Jose do Rio Preto (SJRP); (2) specialized sheep and mountain pasture in Spain (SMP); (3) fully integrated mixed sheep and permanent crops in Spain (SPC); (4) partially integrated mixed sheep and arable in Spain (SAC); (5) Brazilian cattle and sheep system (BCSS); (6) medium farmer cattle and sheep system in Argentina (MACSS); (7) big farmer cattle and sheep system in Argentina (BACSS); (8) grazing cattle in Argentina (GC). Higher circles representing higher total emergy; it was considered the service emergy contribution. Where: (1), data from the research; (2–4) Rodriguez-Ortega et al. [10]; (5–7) Salas et al. [25]; and (8) Rótolo et al. [26].

Thus, the BCSS (5), MACSS (6) and BACSS (7) systems presented long-term sustainability due to a lower F dependence and higher R inputs, whereas the SJRP system presented short-term sustainability due to a higher P dependence and low R inputs. This information confirms the previously discussed findings and indicators. When the percentage of renewability of the systems is analyzed, without considering the renewable fraction of the economy's resources, it can be observed that, despite not showing a high percentage, the SJRP system presented greater renewability than the system with an integration of pasture and crops on the Mediterranean plains of Spain (SAC). However, when the EIR is analyzed, the SJRP system showed a higher value when compared to the other three systems. This is due to its high dependency on the resources of the economy (labor and services), with the environment making little, or a relatively minor, contribution. The use of these kinds of resources impacts directly on the EER, which in this case, shows as being the closest to a fair price compared to other systems. This information highlights the importance of analyzing the indexes in an associated way to better understand the system. When the animals are raised in mountainous regions at higher altitudes, and the environment makes a high contribution to the system, the EER is less than 0, so the system is more efficient in terms of economic costs, and more sustainable in terms of emergy indexes. It is possible to observe the difference between the pasture systems [25,26], where the renewability is greater than the indexes, it shows a more sustainable system. Thus, a more efficient uses of natural resources, instead of the use of non-renewable resources from the economic system, will generate lower levels of environmental pressure [27–29]. Due to this, and to obtain lower EIR and ELR values (dependence on P), it is necessary to increase the contribution of renewable resources within the system.

No Use of Grain in Feedlot Lambs: A Simulation

According to the results, the soyabean meal and corn used as ingredients in finishing the lamb diets represented the most important sources for both the economic and emergy results, corresponding to 11% and 9% of the total cost, and 16% and 11% of all incorporated emergy, respectively. In Galina et al. [30], lambs submitted to exclusive diets of sugar cane presented lower final body weight and lower forage intake when compared to lambs submitted to more complex diets. It is suggested that the lower ruminal pH and lower ammonia production, as well as the absence of continuous proteic or non-proteic nitrogen supplementation (i.e., soybean meal and urea), could explain the inferior performance. Thus, despite the lower final body weight, it is possible to feed lambs with only sugar cane in the finishing phase (~15 kg; 60 days until slaughter). Thus, a lamb feeding program is suggested with no grains (NGLF scenario) and new zootechnical parameters, resulting from this simulation (Supplementary Materials S3 and S4). In the NGLF scenario, the lower forage intake and the exclusion of grains from the feeding program of feedlot lambs implied a reduction of 11% of the total cost when compared to SJRP (original scenario; Table 3). According to the results, the feeding cost (25%) of SRJP was the higher lamb production cost item when compared to the other inputs. Thus, strategies that aim to improve diet efficiency often imply reductions in the lamb production costs and improvements in the net margin. However, in this study, the total revenue for the NGLF scenario was 25% lower than that for SJRP as the revenue is the product obtained between the meat produced and the price paid per kg of animal sold. Thus, considering the lower total revenue, the NGLF scenario showed a net margin 26% lower than that of SJRP, indicating higher profitability in SJRP. Thus, if, on one hand, the exclusion of grains from the feed program of feedlot lambs could reduce the total production cost, the lower final body weight could imply lower profitability.

Table 3. Comparison between emergy indicators in SJRP (original scenario) and in the simulated scenario with no use of grain (NGLF scenario).

Economic Indices				
	Modified Expression	**SJRP**	**NGLF**	**Units**
TR	**	452,298.05	338,033.28	USD
TC	**	34,032.31	30,409.49	USD
Nm	TR − TC	418,265.74	307,623.79	USD
Emergy Indices [1,2]				
UEV	Y/Ep	4.39×10^4	4.32×10^4	sej/J
EYR	Y/F	1.68	1.95	sej/sej
ELR	(N + F)/R	1.49	1.06	sej/sej
ESI	EYR/ELR	1.13	1.84	sej/sej
%Ren	(R/Y) × 100	40	49	%
EIR	F/I	4.49	3.031.83	sej/sej
EER	Y/($ * seJ/$)	0.09	0.09	sej/sej

TR: total revenue; TC: total cost; Nm: net margin; ** see Supplementary Materials S3 and S4; [1] UEV: unit emergy value (transformity); EYR: emergy yield ratio (self-sufficiency); ELR: environmental loading ratio (environmental stress); ESI: emergy sustainability index (sustainability); %Ren: percentage of renewability (renewability); EIR: emergy investment ratio (dependency); EER: energy exchange ratio (delivered emergy); [2] considering emergy indicators with no services.

If, on the one hand, diets with no grains in the feed programs of feedlot lambs could reduce the profitability, on the other hand, it could improve the environmental aspects of the system production, according to the emergy indicators. The emergy indicators pointed out that the scenario with no grains in the feed program of feedlot lambs could improve the sustainability of lamb production systems, decreasing the economic inputs (P), as well as the system's dependence on external inputs. This fact can be deduced from the EIR results. Furthermore, the EIR aim is to compare processes that present more economics from the relation between P inputs and local environmental inputs. Thus, the production system that presented the largest investment in the purchase of inputs presented higher dependency values. However, a higher production cost can lead to a lower profit, and therefore lower competitiveness [9]. According to the results, the lamb production system in the NGLF scenario would be 2.5 times less dependent on F when compared to the lamb production system in the SJRP scenario (EIR = 3.03 and 4.49, respectively), due to it being more competitive and environmentally friendly. To Brandt-Williams and Odum [31], the EIR results are directly related to environmental system aspects as higher F inputs imply higher environmental costs, and vice-versa. Thus, with the decrease in external input dependence, the sheep production system in the NGLF scenario should provide a greater amount of emergy for society (<ELR), a lower environmental load (<ELR), and greater environmental sustainability (>ESI). The lamb production system in the NGLF scenario showed an EYR 29% higher and an ELR two times lower than the lamb production system in the SJRP scenario, meaning the NGLF scenario would be more sustainable than the original scenario (Figure 5).

In the NGFL scenario, the SJRP system showed similar ESI result to the SPC system, a fully integrated system with mixed sheep and permanent crops that fed sheep in forage croplands. In other words, the NGFL scenario appears to make the SJRP system more extensive due to the lower P input dependence. In summary, the simulation results suggest that feeding lambs with no grains makes available more local renewable inputs from the economic inputs with the lower environmental cost being a more sustainable way to conduct a lamb production system. Feeding lambs without grains could also imply a lower body weight and lower profitability. However, not using grains in the feeding program of feedlot lambs could decrease the dependence on external inputs. Thus, the decision to change to a more sustainable way of producing is a holistic decision and must include both economic and environment aspects.

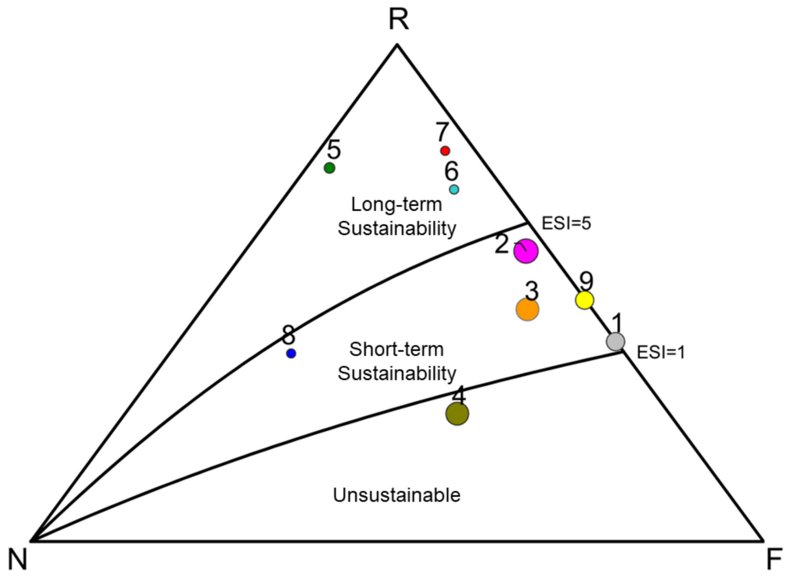

Figure 5. Ternary diagram representing the representative sheep production system from the region of Sao Jose do Rio Preto with or (SJRP original scenario) (1) without grain in lamb feed scenario (9); and comparing to (2) specialized sheep and mountain pasture in Spain (SMP); (3) fully integrated mixed sheep and permanent crops in Spain (SPC); (4) partially integrated mixed sheep and arable in Spain (SAC); (5) Brazilian cattle and sheep system (BCSS); (6) medium farmer cattle and sheep system in Argentina (MACSS); (7) big farmer cattle and sheep system in Argentina (BACSS); (8) grazing cattle in Argentina (GC). Higher circles represent higher total emergy; the service emergy contribution was considered.

Figure 6 shows the relationship between economic (net margin) and emergy (ESI) indicators. From the graph, it can be seen what scenario is a more sustainable system, considering an integrated and holistic vision. According to Bonilla et al. [19], the highest square area would suggest a better way to achieve the sustainability of a system.

In this sense, despite resulting in a lower body weight and lower profitability, no use of grains in the feeding program of feedlot lambs could be a better way to achieve a more sustainable sheep production system due to the lower dependence on external inputs, higher competitiveness, and a lower environmental cost compared with the SJRP system production in the original scenario. Lagerberg and Brown [32] demonstrated that intensive systems demand more materials and services and are highly dependent on the economy. However, these systems can only be considered sustainable if the inputs are considered renewable and efficient use of these sources is made. In addition, the P inputs are reduced.

Furthermore, the intensification of livestock is closely linked to the sustainability of space and time and, according to the same authors, is a relationship of yield and environmental cost. Only through the same base measurement of unit is it possible to recognize the extent that inflows impact the production system, and with this, the cattle producer can change the way they produce animals with the insertion of renewable resources into the system.

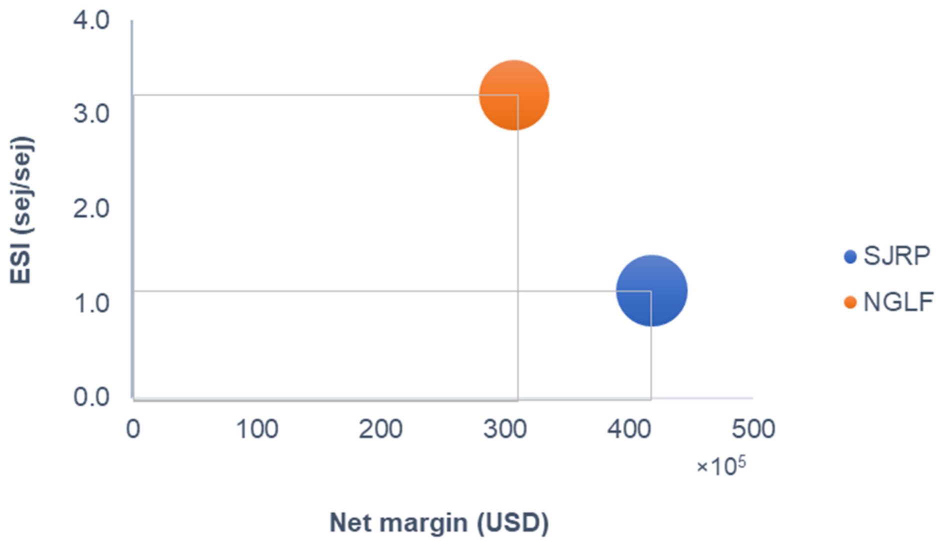

Figure 6. Graphic ESI (sej/sej) vs. net margin (USD) representing the scenarios with (SJRP, original scenario) and without grains (NGLF, simulated) in the feeding program of feedlot lambs in a representative Brazilian lamb production system (São Paulo, Brazil). The highest square area represents a better performance for the sheep production system. The lowest square area represents a poor performance for the sheep production system. SJRP: São José do Rio Preto original scenario; NGLF: no grain in feeding program of feedlot lamb scenario; ESI: emergy sustainability index. The circumference is related to the transformity (Tr; 4.39×10^4 and 4.32×10^4 for SJRP and NGLF, respectively).

5. Conclusions

In conclusion, the current state of the Brazilian sheep production system analyzed (in São José do Rio Preto, São Paulo state) is not sustainable due to the high level of emergy from outside flows; it is highly dependent on outside economic inputs and has a high environmental impact. To become more renewable and have less environmental impact, there should be a rethink of the system; the main aspect that exhibits a lack of sustainability is the feedlot lambs that consume high levels of concentrate (corn and soybean) from outside the system. This strategy of confining lambs allows the lambs to be ready for consumption faster (the slaughter age is around 130 days), with the live weight at slaughter being approximately 38 kg. According to the simulation, not using grains in the feeding program of feedlot lambs could be a strategy to improve sustainability and make the product more competitive, despite a lower lamb body weight and lower profitability.

Another possible strategy to improve the system's sustainability is to produce those inputs that are the most used, such as corn, soybean, and sugar cane forage. The last one, although it represents just 9% of the total emergy in the system, could be grown on the farm. However, for this strategy to succeed, some level of investment will be necessary. Investment in machinery, labor, diesel fuel, technical assistance, and other inputs from outside the system will improve the self-catalytic feedback cycles inside the system, which is essential for improving the sustainability of the system. This fact suggests that the exclusion of grains from the feeding program of feedlot lambs could be the easiest strategy to make the studied lamb production system more sustainable.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su132111595/s1. S1: Representative property of the region São José do Rio Preto; S2: The environmental and economic flows in the sheep system, expressed both in emergy flow and financial value of emergy (Em$Dollar); S3: Representative property of the region São José do Rio Preto simulating no grains in lamb feed; S4: The environmental and economic flows in the sheep system, expressed both in emergy flow and financial value of emergy (Em$Dollar) simulating no grains in lamb feed.

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