Scientific Paper

Evaluation of energy sustainability in a conventional dairy agroecosystem

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Abstract

Objective: To evaluate the energy sustainability of milk production in a conventional agroecosystem.

Materials and Methods: The system diagram was designed according to the energy flows involved in the productions of two consecutive years. The energy invested in obtaining the materials and services used to produce milk was determined and the traditional and modified energy performance indexes were calculated and interpreted: transformity, renewability, energy yield ratio, energy investment ratio, environmental load ratio and sustainability index. Economic indicators were determined: net income, total costs, gross profit and profit/cost ratio.

Results: The energy indicators showed that under the current production model the agroecosystem is unsustainable (0,9) over time. High energy costs (2,98 E+06 and 3,28 E+06 seJ/J), low support from renewable sources (33,8 and 38,5 %), adequate potential to produce primary energy (1,51 and 1,63), high dependence on external resources (1,96 and 1,60) and low environmental impact (1,96 and 1,60) were recorded. However, the classical economic analysis showed profitability of the system (2,12 and 1,80 CUP).

Conclusions: The energy indicators expressed the inability of the agroecosystem to sustain itself over time under a conventional design of production. The classical economic analysis demonstrated the profitability of the agroecosystem; while the energy synthesis evaluation indicated that it is unsustainable

Keywords: economic analysis, energy, milk production

Introduction

The dairy sector is an important link in the Cuban agricultural scenario, due to the nutritional quality of this foodstuff and its high demand. In 2019, national production reached 491 300 000 kg (ONEI, 2020). However, these volumes do not meet the requirements of the population or the industry, so the country is forced to invest millions of dollars annually in importing significant quantities of dairy products (ONEI, 2021), an aspect that turns milk production into a matter of national security.

In Cuba, the management of these systems from a productivist perception prevails, which simplifies ecosystemic functioning and increases dependence on external energy resources, posing a threat to sustainability. Subsequently, it represents the fundamental line in the development strategy of Cuban animal husbandry, whose recovery and growth are premises to transform the current agricultural panorama (Acosta *et al*., 2017) into a model that ensures its production, access and consumption throughout the year (Carmenate *et al*., 2019).

Based on this premise, energy synthesis is presented as a methodology that allows the integration of ecological and economic systems in quantitative terms, with the use of energy as a common language (López-Bastida *et al*., 2018). This methodology favors the characterization of the main energy sources external to the system, which direct its evolution; estimation of the contribution of ecosystem services to the socioeconomic system as natural capital; appreciation of the work of the ecosphere in the global dynamics of anthropic systems and performance of integrated economic-ecological environmental accounting on thermodynamic bases, with the objective of contributing to political decision-making and the calculation of thermodynamic indicators of yield, impact and sustainability (Nielsen, 2019).

This methodology constitutes a complement to cover the complex interrelationships between finance and the environment in which food systems operate (Giampietro *et al*., 1994) and allows the evaluation of agroecosystems, with a strong scientific component (thermodynamic and ecological) of the

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interdependence relationships established between natural systems and socio-economic systems.

As part of the development program in which the scientific-technological and productive farm El Guayabal is involved, in order to transform its current panorama into a scenario on sustainable bases, the study of its different subsystems from a holistic vision, which favors decision-making aimed at a harmonious operation, is urgent. The objective of this study was to evaluate the sustainability of milk production through the application of energy synthesis.

Materials and Methods

Study locality. The research was carried out in a dairy farm belonging to the scientific-technological and productive direction El Guayabal, located at 23°00'12.5" North latitude and 82°09'57.9" West longitude, in the San José de Las Lajas municipality, Mayabeque province, Cuba. The unit has an area of 36 ha, with a typical Ferralitic red soil in all its extension, flat relief and 120 meters above sea level, according to the global positioning system (GPS). The climate variables recorded over the last five years showed average annual temperatures and rainfall of 24,3 ºC and 129,9 mm, respectively. Relative humidity ranged from 72,8 % (minimum, in March) to 84,6 % (maximum, in December); while wind speed did not exceed 5,46 km/h.

Data collection. Information collection was carried out by means of non-participatory observation (comprehensive functioning diagnosis of the area under study, analysis of historical data records), semi-structured interviews with key informants and random interviews with farmers, in order to seek triangulation of information. Previously, a survey of the tools was carried out to assess their feasibility.

Herd and pasture areas. The total cow stock was 49 and 57 heads in 2018 and 2019, respectively, with an annual average of 24 milking animals in both periods, overall stocking rates of 1,43 and 1,66 LAU.ha^{-1} and average calving-calving intervals of 468 and 519 days. The production per milking cow was 5,00 and 4,28 kg/day, for an annual yield of 1 216,82 and 1 042,48 kg ha^{-1} of milk (density: 1,0289 kg/L), which is the only agricultural product obtained in the farm. The racial groups were represented by 67,8 % Siboney de Cuba, 28,81 % Siboney crossbreds and 3,39 % other dairy crosses. In the pasture areas, the highest abundance (51 %) among botanical species was for bahiagrass (*Paspalum notatum* Flüggé.). For forage production, 0,8 ha of king grass CT-115 (*Cenchrus purpureus* (Schumach) Morrone) were sown annually. Rotational grazing is applied with 62 paddocks and two daily milking moments (morning: 5:00-6:00 a.m.; afternoon: 3:00 p.m.-4:00 p.m.).

Evaluation of energy synthesis. It was developed in the four stages proposed by Odum (1996):

Systemic diagram. With the information obtained in the data collection, the limits, components, inputs and outputs of the system were represented, as well as the energy and material flows, and the interactions among components. Thus, the complexity of the system during 2018 and 2019 was expressed using the universal symbols established by Odum (1996). In the different stages of the methodology, the total energy (Y) was broken down; considering the resources of nature (I), as renewable (R) and non-renewable (N); and the resources of economy (F), as materials (M) and services (S).

Energy synthesis table. The flows represented in the systemic diagram were converted into a calculation line in the energy evaluation table. The solar energy of the goods and services involved in the production was calculated by considering the amount with which each flow entered the system, its transformity, renewable fraction and conversion factor. Thus, the different energy qualities were weighted and expressed in solar joules (seJ).

Energy indexes. The traditional and modified energy performance indexes were calculated and interpreted: transformability, renewability, energy performance ratio, energy investment ratio, environmental load ratio and sustainability index (table 1). The indexes were processed using the EmTable computer system (Ortega, 2005).

Economic analysis. The financial performance of the dairy farm was evaluated based on the indicators proposed by Funes-Monzote (2009): net income from production, gross profit and profit/cost ratio (table 2). In the calculation of total production costs, fixed and variable costs were considered: raw materials and supplies (feedstuffs, construction materials, medicines and related materials, materials and consumables, implements and tools, parts and spare parts), fuels (diesel, lubricants and oils), energy, salaries, depreciation of fixed assets and professional services.

Results and Discussion

Figure 1 shows the main energy flows involved in the farm's milk production during the years

Table 1. Evaluated energy indexes.

Energy indexes	Expression	Concept
Solar transformity	Tr=Y/EP	Total energy / energy of the resource
Renewability Modified R, %	% R=100(R/Y) % R*=100[(R+Mr+Sr)/Y]	Renewable inputs / total energy
Energy yield ratio Modified EYR	EYR=Y/F EYR*=Y/Fn	Total energy / economy resources
Energy investment ratio Modified EIR	EIR=F/I EIR*=Fn/(I+Fr)	Economy resources / nature resources
Environmental load ratio Modified ELR	ELR=(N+F)/R ELR*=(N+Mn+Sn)/(R+Mr+Sr)	(Non-renewable resources + economy resources) / renewable resources
Energy sustainability index Modified ESI	ESI=EYR/ELR ESI*= EYR*/ELR*	(Total energy / economy resources) / [(non-renewable resources + economy resources) / renewable resources]

Energy indexes. Modified energy indexes were calculated and interpreted. Sub-indexes: **r**- renewable; **n**- non-renewable.

Table 2. Economic indicators (Thousands CUP/ha/year).

Indicator	Expression
Net production income	Incomes for milk concept
Gross profit	Net income production – total production costs (fixed costs + variable costs)
Profit/cost ratio	Net production income / total production costs (fixed costs + variable costs)

CUP: Cuban peso

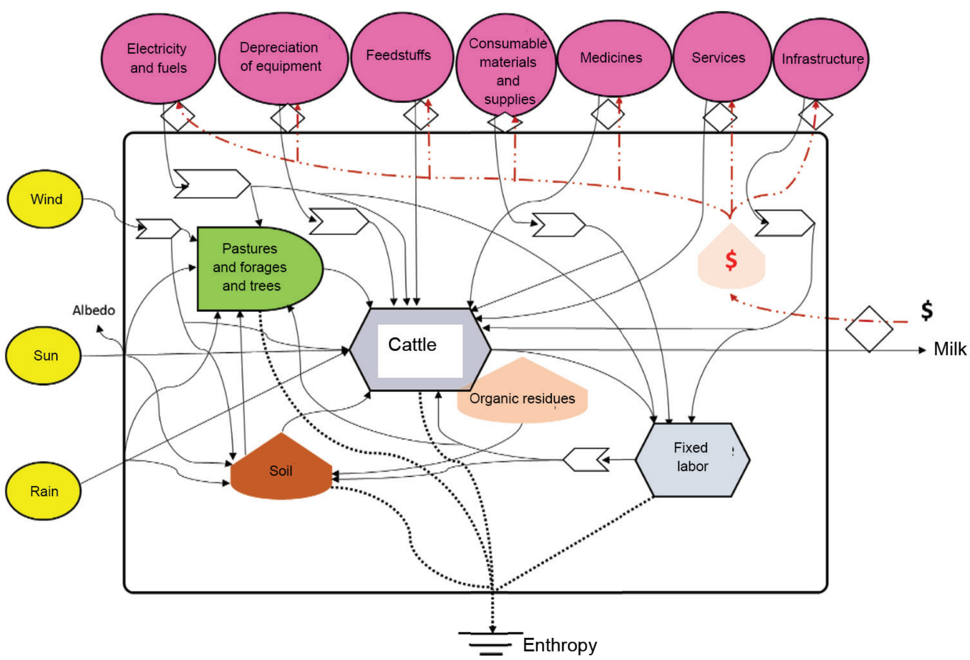

Fig. 1. Simplified diagram of energy flow in the dairy farm.

of the study. Energies from the sun, rainfall and wind basically drive the other system flows, as they comprise the inputs from renewable sources of nature. The most representative imports came from the resources of the economy (materials and services) and involved electricity, fuels, depreciation of equipment, feedstuffs, consumer goods, medicines, technical-professional services and infrastructure materials.

Biocenosis and biotope factors were identified as internal components of the system, which were kept within the limits: pasture and forage, trees, cattle, labor and soil. The diagram shows low trophic complexity, as well as incorporation into the soil of the organic residues obtained from excrement. The only product of commercial and food interest generated in the unit is milk. This is the only source of economic income, from which materials and services of economy must be guaranteed.

The inputs corresponding to year 1 are shown in table 3, where the renewable resources of nature represented only 3,1 % of the total energy. The materials of economy accounted for 42,1 % of the investments in terms of energy, with the use of feedstuffs (15,9 %) and electricity (9,8 %) standing out. The services of economy represented the largest input to the system (54,8 %), due to the high proportion of energy used in fixed labor and contracted professional services. The energy invested in infrastructure was negligible and did not reach a percentage value.

During this year, 3 066,38 E+12 seJ/ha/year of renewable energy was used, which represented 33,8 % of the total energy used. Activities related to services contributed the highest amount of renewable energy (2 213,54 E+12 seJ/ha/ha/year).

Table 4 shows the energy analysis for year 2. Renewable resources from natural sources accounted for 3,2 % of total energy; while materials and services of economy accounted for 35,5 % and 61,31 %, respectively. Elements used for infrastructure maintenance accounted for 0,03 %. A total of 5 257,47 E+12 seJ/ha/year of non-renewable energy was used, which corresponds to 61,5 % of the total and indicates insufficient use of renewable sources.

There was a similar trend to the previous year, in that the largest renewable contributions were generated in the services of the economy, as these contributions had a renewable fraction of 0,60. This concept also accounted for the highest non-renewable inputs, as the work routines performed by livestock farmers required 454,7 hours/ha/year. This high value proves the intensification of agricultural production, sustained by productive specialization, simplification of livestock management and high use of external inputs, which according to Reinoso-Pérez *et al*. (2019) is one of the main causes of the loss of regulating and supporting ecosystem services.

The energy synthesis tables show the existence of flows that, expressed in energy units (seJ/ha/year), were higher than others that exceeded it in surface units. For example, if we compare the import of soybean (*Glycine max* Merr.) raw material corresponding to 32,7 kg/ha/year, with the 3,39 kg/ha/year of concentrate feed used for pigs in maintenance, it can be noted that the latter used 10,94 E+12 seJ/ha/year more than soybean (table 4). This is due to the fact that the amount of potential energy required to obtain concentrate feed is higher, since the industrial process involves greater use of resources and, consequently, its hierarchical position in energy terms is higher (higher transformity).

Energy inputs to the system during year 1 exceeded those of year 2 by 523,55 E+12 seJ/ha/year. The difference was marked by the superiority in terms of economy materials used (fig. 2). In both periods, economy services corresponded to the highest energy amounts, while renewable resources of natural origin did not involve expenditures exceeding 300,00 E+12 seJ/ha/ha/year and infrastructure investments remained below 3,00 E+12 seJ/ha/ha/year.

During year 1 (table 5), the system needed 2,98 E+06 seJ to produce each J of energy contained in milk. In 2019, this value rose to 3,28 E+06 seJ/J, indicating that higher amounts of energy transformations were performed than in the preceding period, i.e., higher energy expenditure. Although the total energy used was lower, the energy generated in the product was also reduced, with a difference between both years of 0,43 J/ha/year.

The Y/EP ratio showed that the decrease in energy inputs originated a directly proportional behavior in yields. During 2019, there was a considerably lower import of raw materials destined for animal feed, so the livestock ration was limited to the available resources, which, being scarce, caused production damage (table 6). This indicates that the productivity of the system depended, to a large extent, on external resources and, in the absence of any, the results were compromised.

Table 3. Energy synthesis of the farm, year 1.

Indicator	Contributions	Renewable fraction	Flow	Unit	Factor	Transformity seJ/unity	Renewable energy E+12 seJ/ha/year	Non-renewable energy E+12 seJ/ha/year	Total energy E+12 seJ/ha/year	%
Renewable resources of nature (R)							280,684	0,000	280,684	3,10
R1	Sun	1,00	1460,00	kWh/m^2/year	3,60E+10	1,00 (a)	52,560	0,000	52,560	0,58
R2	Wind	1,00	1,17	m/s	1,47E+10	2,45E+03 (b)	42,124	0,000	42,124	0,46
R3	Rain	1,00	0,12	m^3/m^2/year	5,00E+10	3,10E+04 (b)	186,000	0,000	186,000	2,05
Materials of economy (M)							572,15	3244,57	3816,72	42,09
M1	Consumable materials and supplies	0,80	115,01	$/ha/year	1,00	5,40E+12 (c)	496,843	124,211	621,054	6,85
M2	Medicines and related materials	0,00	45,89	$/ha/year	1,00	5,40E+12 (c)	0,000	247,806	247,806	2,73
M3	Salt	0,05	1,80	kg/ha/year	1,00	2,00E+12 (c)	0,180	3,420	3,600	0,04
M4	Molasses, urea, bagasse	0,00	69,44	kg/ha/year	1,00	2,08E+12 (c)	0,000	144,435	144,435	1,59
M5	Calcium	0,05	4,44	kg/ha/year	1,00	1,68E+09 (d)	0,000	0,007	0,007	0,00
M6	Phosphate	0,05	4,88	kg/ha/year	1,00	3,70E+10 (d)	0,009	0,172	0,181	0,00
M7	Raw material, corn	0,17	78,23	kg/ha/year	1,00	2,08E+09 (b)	0,000	0,163	0,163	0,00
M8	Raw material, soybean	0,17	63,12	kg/ha/year	1,00	3,26E+09 (b)	0,000	0,206	0,206	0,00
M9	Byproduct	0,00	139,96	kg/ha/year	1,00	3,26E+12 (c)	0,000	456,270	456,270	5,03
M10	Mineral core	0,00	0,21	kg/ha/year	1,00	3,26E+12 (c)	0,000	0,685	0,685	0,01
M11	Vitamin core	0,00	0,1	kg/ha/year	1,00	3,26E+12 (c)	0,000	0,326	0,326	0,00
M12	Wheat bran	0,00	14,86	kg/ha/year	1,00	3,26E+12 (c)	0,000	48,444	48,444	0,53
M13	Fish meal	0,00	10,95	kg/ha/year	1,00	3,26E+12 (c)	0,000	35,697	35,697	0,39
M14	Dairy cow concentrate feed	0,00	93,07	kg/ha/year	1,00	3,26E+12 (c)	0,000	303,408	303,408	3,35
M15	Pig concentrate feed, starter	0,00	6,25	kg/ha/year	1,00	3,26E+12 (c)	0,000	20,375	20,375	0,22
M16	Pig concentrate feed, maintenance	0,00	0,96	kg/ha/year	1,00	3,26E+12 (c)	0,000	3,130	3,130	0,03
M17	Laying hen concentrate feed, light line	0,00	84,13	kg/ha/year	1,00	3,26E+12 (c)	0,000	274,264	274,264	3,02
M18	Starter chicken concentrate feed, heavy line	0,00	0,61	kg/ha/year	1,00	3,26E+12 (c)	0,000	1,989	1,989	0,02

Table 3.Continuation.

Indicator	Contributions	Renewable fraction	Flow	Unit	Factor	Transformity seJ/unity	Renewable energy E+12 seJ/ha/year	Non-renewable energy E+12 seJ/ha/year	Total energy E+12 seJ/ha/year	%
M19	Growing chicken concentrate feed, heavy line	0,00	1,94	kg/ha/year	1,00	3,26E+12 (c)	0,000	6,324	6,324	0,07
M20	Broiler concentrate feed, finish fattening	0,00	41,59	kg/ha/year	1,00	3,26E+12 (c)	0,000	135,583	135,583	1,50
M21	Multinutritional block	0,00	2,78	kg/ha/year	1,00	3,26E+12 (c)	0,000	9,063	9,063	0,10
M22	Cow multiple premixture	0,00	0,41	kg/ha/year	1,00	3,26E+12 (c)	0,000	1,337	1,337	0,01
M23	Electricity	0,05	913,33	kWh/ha/year	3,60E+06	2,69E+05 (b)	44,223	840,245	884,469	9,75
M24	Lubricants	0,01	0,59	kg/ha/year	1,00	9,21E+04 (b)	0,000	0,000	0,000	0,00
M25	Diesel	0,01	28,18	L/ha/year	1,00	9,21E+04 (b)	0,000	0,000	0,000	0,00
M26	Equipment depreciation	0,05	167	$/ha/year	1,00	3,70E+12 (b)	30,895	587,005	617,900	6,81
Services of Economy (S)							2213,54	2756,09	4969,64	54,81
S1	Fixed labor	0,60	631,28	$/ha/year	1,00	3,30E+12 (b)	1249,934	833,290	2083,224	22,97
S2	Professional services	0,60	486,67	$/ha/year	1,00	3,30E+12 (b)	963,607	642,404	1606,011	17,71
S3	Human work	0,00	4,55E+08	J/ha/year	1,00	1,20E+06 (a)	0,000	546,000	546,000	6,02
S4	Animal work	0,00	6,12E+08	J/ha/year	1,00	1,20E+06 (a)	0,000	734,400	734,400	8,10
Infrastructure (Inf)					V.U (year)		0,00	0,43	0,43	
IF1	Implements and tools	0,00	4,5	$/ha/year	1,00	5,40E+12 (c)	0,000	0,413	0,413	0,00
IF2	Parts and spare parts	0,00	0,19	$/ha/year	1,00	5,40E+12 (c)	0,000	0,017	0,017	0,00
Total (Y)							3066,38	6001,09	9067,47	

a) Odum (1996), b) Agostinho *et al*. (2019), c) Bassan *et al*. (2015), d) Cavalett *et al*. (2004)

Table 4. Energy synthesis of the farm. Year 2.

Indicator	Contributions	Renewable fraction	Flow	Unit	Factor	Transformity, seJ/unit	Renewable energy, E+12 seJ/ha/year	Non-renewable energy, E+12 seJ/ha/year	Total energy, E+12 seJ/ha/year	%
Renewable resources of nature (R)							274,20	0,00	274,20	3,21
R1	Sun	1,00	1460,00	kWh/m^2/year	3,60E+10	1,00 (a)	52,560	0,000	52,560	0,62
R2	Wind	1,00	0,99	m/s	1,47E+10	2,45E+03 (b)	35,643	0,000	35,643	0,42
R3	Rain	1,00	0,12	m^3/m^2/year	5,00E+10	3,10E+04 (b)	186,000	0,000	186,000	2,18
Materials of economy (M)							637,57	2391,15	3028,72	35,45
M1	Consumable materials and supplies	0,80	132,10	kg/ha/year	1,00	5,40E+12 (c)	570,672	142,668	713,340	8,35
M2	Medicines and related materials	0,00	94,87	$/ha/year	1,00	5,40E+12 (c)	0,000	512,298	512,298	6,00
M3	Salt	0,05	0,64	kg/ha/year	1,00	2,00E+12 (c)	0,064	1,216	1,280	0,01
M4	Molasses, urea, bagasse	0,00	128,23	kg/ha/year	1,00	2,08E+12 (c)	0,000	266,718	266,718	3,12
M5	Calcium	0,05	3,43	kg/ha/year	1,00	1,68E+09 (d)	0,000	0,005	0,006	0,00
M6	Phosphate	0,05	4,43	kg/ha/year	1,00	3,70E+10 (d)	0,008	0,156	0,164	0,00
M7	Raw material, soybean	0,00	32,71	kg/ha/year	1,00	3,26E+09 (b)	0,000	0,107	0,107	0,00
M8	Byproduct	0,00	49,25	kg/ha/year	1,00	3,26E+12 (c)	0,000	160,555	160,555	1,88
M9	Maintenance pig concentrate feed	0,00	3,39	kg/ha/year	1,00	3,26E+12 (c)	0,000	11,051	11,051	0,13
M10	Light-line laying hens concentrate feed	0,00	3,00	kg/ha/year	1,00	3,26E+12 (c)	0,000	9,780	9,780	0,11
M11	Cow multiple pre-mixture	0,00	0,18	kg/ha/year	1,00	3,26E+12 (c)	0,000	0,587	0,587	0,01
M12	Starter calf concentrate feed	0,00	4,84	kg/ha/year	1,00	3,26E+12 (c)	0,000	15,778	15,778	0,18
M13	Nuprovim-10	0,00	0,17	kg/ha/year	1,00	3,26E+12 (c)	0,000	0,554	0,554	0,01
M14	Electricity	0,05	913,33	kWh/ha/year	3,60E+06	2,69E+05 (b)	44,223	840,245	884,469	10,35
M15	Lubricants	0,01	0,32	kg/ha/year	1,00	9,21E+04 (b)	0,000	0,000	0,000	0,00
M16	Diesel	0,01	10,65	L/ha/year	1,00	9,21E+04 (b)	0,000	0,000	0,000	0,00
M17	Equipment depreciation	0,05	122,17	US$/ha/year	1,00	3,70E+12 (b)	22,601	429,428	452,029	5,29

Table 4. Continuation.

Indicator	Contributions	Renewable fraction	Flow	Unit	Factor	Transformity, seJ/unit	Renewable energy, E+12 seJ/ha/year	Non-renewable energy, E+12 seJ/ha/year	Total energy, E+12 seJ/ha/year	%
Services of economy (S)							2374,67	2863,52	5238,19	61,31
S1	Fixed labor	0,60	716,17	$/ha/year	1	3,30E+12 (b)	1418,017	945,344	2363,361	27,66
S2	Professional services	0,60	447,03	$/ha/year	1	3,30E+12 (b)	885,119	590,080	1475,199	17,27
S3	Maintenance and repair services	0,60	36,13	$/ha/year	1	3,30E+12 (b)	71,537	47,692	119,229	1,40
S4	Human work	0,00	4,55E+08	J/ha/year	1,00	1,20E+06 (a)	0,000	546,000	546,000	6,39
S5	Animal work	0,00	6,12E+08	J/ha/year	1,00	1,20E+06 (a)	0,000	734,400	734,400	8,60
Infrastructure (Inf)					V.U (year)		0,00	2,81	2,81	0,03
IF1	Implements and tools	0,00	4,03	$/ha/year	1,00	5,40E+12 (c)	0,000	0,605	0,605	0,01
IF2	Parts and spare parts	0,00	14,71	$/ha/year	1,00	5,40E+12 (c)	0,000	2,207	2,207	0,03
	Total (Y)						3286,44	5257,47	8543,92	

a) Odum (1996), b) Agostinho *et al.* (2019), c) Bassan *et al.* (2015), d) Cavalett *et al.* (2004)

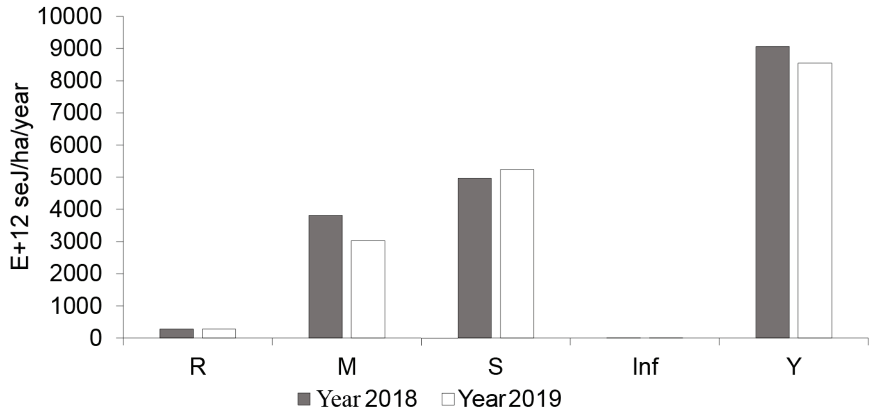

Figure 2. Representativeness of the contributions used by the system.
R: renewable resources, M: material resources, S: service resources, Y: total energy:
Inf: infrastructure investments.

Table 5. Energy performance indicators.

Indicator	Expression	Unit	Value	
			Year 1	Year 2
Tr	Tr=Y/EP	seJ/J	2,98E+06	3,28E+06
% R	% R=100(R/Y)	%	3,10	3,21
% R*	% R=100[(R+M_R+S_R)/Y]	%	33,82	38,47
EYR	EYR=Y/F	adimensional	1,03	1,03
EYR*	EYR*=Y/Fn	adimensional	1,51	1,63
EIR	EIR=F/I	adimensional	31,30	30,16
EIR*	EIR*=Fn/(I+Fr)	adimensional	1,96	1,60
ELR*	ELR*=(N+MN+SN)/(R+MR+SR)	adimensional	1,96	1,60
ESI*	ESI*= EYR*/ELR*	adimensional	0,77	1,02
Y	Y=I+F	sej/ha/year	9,07E+15	8,54E+15
EP	EP=Pa*CV/A	J/ha/year	3,04E+09	2,61E+09

Pa: annual production, CV: caloric value of milk=2.5 MJ/kg (Funes-Monzote, 2009), A: area, Tr: solar transformity, % R: renewability, % R*: modified R, %, EYR: energy yield ratio, EYR*: modified EYR, EIR: energy investment ratio, EIR*: modified EIR, ELR*: modified environmental load ratio, ESI*: modified energy sustainability index, Y: total energy, EP: energy of the resource

Table 6. Productivity per milk concept.

Year	kg/year	J/kg	J/year	J/ha/year	kg/ha/year
1	43 805,42	2,50E+06	1,10E+11	3,04E+09	1 216,82
2	37 529,13	2,50E+06	9,38E+10	2,61E+09	1 042,48

The low biological diversity in the system is a probable cause of the low agricultural and energy productivity achieved, according to Cevallos-Suarez *et al.* (2019). In addition, the availability of bulky feedstuffs in the farm was scarce, due to a low population of quality pastures, high rate of infestation by weeds and the fact that sowing was not carried out for long periods. Likewise, forage production was limited, the population of tree and shrub species was poor, and no hay or silage was produced to compensate for the scarcity of feedstuffs during the dry season. These deprivations jeopardize the feed security of livestock and make it necessary to look for alternatives outside the borders of the system.

The quality of the agroecosystem depends on the extent to which less energy conversion is required to obtain the product. In this sense, the key is to generate the greatest amount of energy in the products at the lowest possible energy cost, which implies independence from external sources.

The % R indicates the percentage that renewable energy from nature represents of the total energy used by the system. High values indicate greater possibilities of self-maintenance over time, and therefore constitute a measure of sustainability. The %R* (modified) includes, in addition to renewable natural resources, the renewable fraction of the remaining inputs to the system.

The results (table 5) showed that the unit's capacity to sustain itself from natural components did not exceed 3,10 % (year 1) and 3,21 % (year 2) of the total energy used. When including in the analysis the renewable elements used by the economy (R*), there was an increase of 30,7 and 35,3 in years 1 and 2, respectively, which means that the renewable support of the system was only 33,8 and 38,5 % during each period. This performance also indicates the scarce use of renewable energy sources from nature: the sun, rainfall and wind. Even the partial renewability generated by materials and services was higher than that offered by nature.

The increase in this indicator from one year to the next was due to the decrease in the volumes of non-renewable resources used. Among these, the difference was marked by materials of economy (fig. 3). However, the percentages were lower than those published by Bassan *et al.* (2015), who considered as low a traditional renewability of 14,5 % obtained in a dairy scenario that they classified as unsustainable. Pozo *et al.* (2014) found that banana agroforestry productions can show better % R (68,4 %) than conventional ones (29,3 %).

It has been shown that different productive conceptions in dairying can vary the renewable potential of the systems and, consequently, their sustainability over time. For example, a conventional design in Sweden recorded % R* of 2,12 % (Brandt-Williams and Fogelberg, 2004). Meanwhile, in Brazil, a small-scale family farm with extensive management obtained renewability higher than 28,9 % (Agostinho *et al*., 2019).

Allegretti *et al*. (2018) assert that the origin and nutritional quality of animal feed sources influence the renewability potential of agroecosystems and, consequently, their sustainability.

The two variants by which the index was calculated demonstrated the inefficient management of resources in the farm. This departs from the report by Suárez-Hernández *et al*. (2018), who assert that, by minimizing the use of external inputs, especially those with high energy costs, a positive energy balance is achieved and energy efficiency is increased. Agricultural systems, which seek to maximize the use of renewable energy sources to increase productivity, should achieve high productivity, which is equated to high energy use efficiency (Santagata *et al.,* 2020).

The obtained EYR indicates that both years had similar potentials to export milk from the total

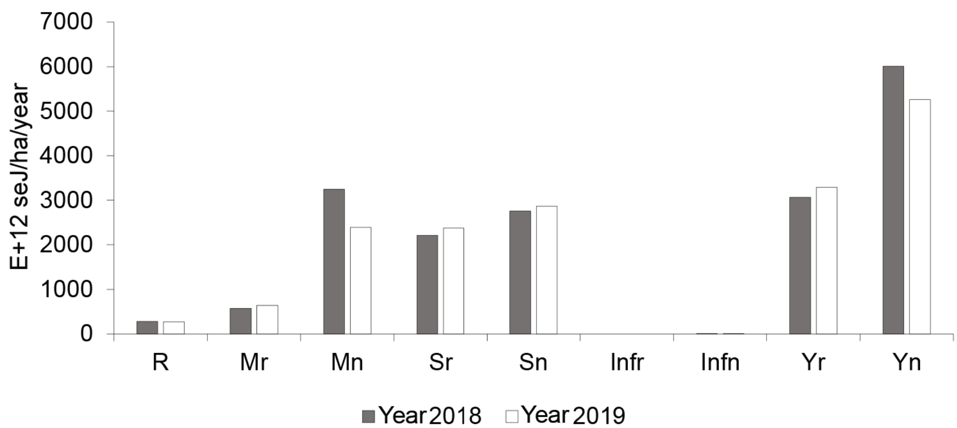

Fig. 3. Incidence of renewable and non-renewable contributions.

R: renewable resources, Mr: renewable material resources, Mn: non-renewable material resources, Sr: renewable service resources, Sn: non-renewable service resources, Infr: renewable infrastructure, Infn: non-renewable infrastructure, Yr: renewable energy, Yn: non-renewable energy.

resources invested from economy. Although the value was close to the unit, the system expressed potential to produce primary energy. The modified EYR suggests that during 2019 there was greater opportunity to withdraw energy by added non-renewable energy. This is because in that year the Fr/Fn ratio was shown at 0,57, being higher than 2018 (0,46). However, it is important to highlight that in neither of the two periods did the renewable fraction reach the unit for each non-renewable element used (fig. 4). In small-scale dairy farming (Agostinho *et al*., 2019), higher capacity to produce primary energy has been demonstrated, with EYR* of 1,72.

According to the EIR, in the two evaluated years, the system had high external dependence, because 31,30 and 30,16 economic units were required for every energy unit of natural origin. Meanwhile, the modified indicator showed the use of 1,96 and 1,60 non-renewable units for every renewable unit. These values indicate the low performance of the system. The most unfavorable condition was observed in 2018, as higher non-renewable energy expenditure was necessary. As reference, in literature it is stated that natural systems have EIR equal to zero (Agostinho *et al*., 2019).

In this animal husbandry activity, traditional EIRs have been assessed as little competitive, significantly lower than those obtained in this research, with indexes of 3,00 (Wada and Ortega, 2003) and 5,73 (Bassan *et al*., 2015). Rainfed agricultural productions have been more efficient than applying irrigation (0,18 *vs*. 0,34 EIR*), since production costs were reduced (Feitosa *et al*., 2019). Meanwhile, integrated pork, fish and grain production has been more successful (2,28 EIR*) than independently (4,61 *vs*. 3,21 *vs*. 2,68 EIR*, respectively) (Cavalett *et al*., 2004).

The ELR* indicators corresponding to 1,96 and 1,60 in 2018 and 2019, respectively, indicate low impact of the system on the environment, according to Maiolo *et al*. (2021). These authors state that ELR values lower than 2,00 indicate low impact, between 2,00 and 10,00 moderate impact and higher than 10,00 are associated with farms with high environmental impact. Bassan *et al*. (2015) classified a dairy system with ELR* equal to 5,92 as of high impact.

It is imperative that the system operates with the least possible negative impact on the surrounding ecosystem. According to what has been observed, the studied scenario shows among its main problems the use of synthetic feedstuffs, which demand higher economy and imply an increase in greenhouse gas emissions, as a result of the enteric fermentation of cattle. This, in turn, is a cause of the deficient systemic design used, because the potential of the farm is not utilized to incorporate alternative practices to conventional cattle raising, based on an agroecological approach on sustainable bases.

Through productive intensification of bean (*Phaseolus vulgaris* L.) cultivation, Asgharipour

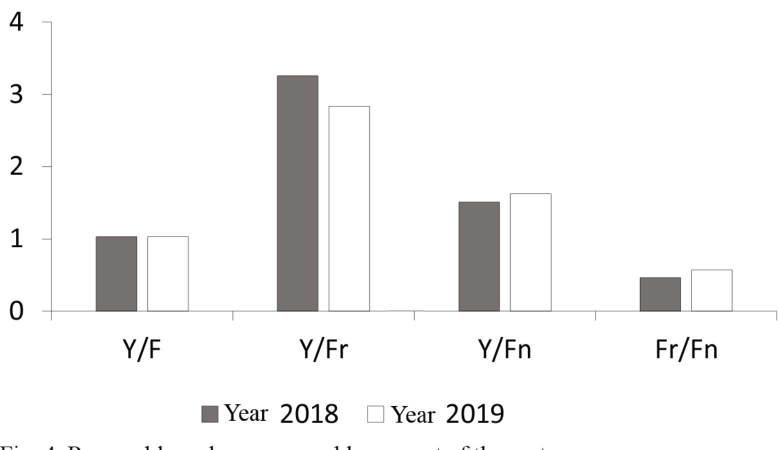

Fig. 4. Renewable and non-renewable support of the system.
Y/F: total energy / economy resources ratio, Y/Fr: total energy / renewable economy resources ratio, Y/Fn: total energy / non-renewable economy resources ratio, Fr/Fn: renewable economy resources / non-renewable economy resources ratio, Fr/Fn: renewable economy resources / non-renewable economy resources ratio.

et al. (2019) proved that ecological systems cause less environmental degradation (0,86 ELR*) than low (11,47 ELR*), moderate (20,00 ELR*) and high range (28,81 ELR*) input import systems. Similarly, banana agroforestry designs caused less environmental stress (0,46 ELR*) than conventional ones (2,41 ELR*) (Pozo *et al*., 2014).

According to the Energy Sustainability Index (ESI), during 2018, milk production based on high inputs was unsustainable. In 2019, this indicator showed improvement as a result of the reduction of industrial feedstuffs. However, the average between the two periods maintained an unfavorable condition with an ESI* of 0,90. This indicates that this production system does not guarantee sustainability over time, because the alterations caused to the environment are high when compared with the primary energy that the scenario makes available to society. These values coincide with those reported by Bassan *et al*. (2015) in dairy farms under similar management conditions, who obtained an ESI* of 0,20.

Given the characteristics of dairy farm 021, framed in a specialized approach to production, it becomes evident that the energy synthesis evaluation will show as general result the unsustainability of the system, because many of the indicators that define it are outside the desired indicators.

Summarizing, it can be said that the percentage of external inputs used for production was high. The potential for using renewable energy sources associated with appropriate technologies was low. The percentage of energy used from on-farm resources only included limited fodder production with seeds obtained in the process itself and the occasional fertilization of those areas with manure. There was no diversification in production and labor intensity was high. No initiatives were promoted by the farmers and the competent authorities (since it is a state organization) to incorporate practices on sustainable bases.

Economic evaluation. Total production costs were higher during 2018 (table 7). Expenditures on raw materials and supplies, mainly those related to consumables, stood out. This is in correspondence with the results of energy performance, where the highest energy expenses were a consequence of food imports. In both years, salary expenses also stood out, which represented the largest outflows in 2019, equivalent to 720 CUP/ha.

The price of milk is defined based on the quality shown by density and mastitis analyses. In the case of being within the desired indicators, the price is 4,50 CUP/L, and in the opposite situation it is penalized at 2,40 CUP/L. Sales to dairy workers are made at 0,25 CUP/L and to service providers at 1,00 CUP/L. These prices allowed that, in spite of the productive costs and the low yields achieved, the gross profit from production was 2,410 and 1,560 CUP/ha in years 1 and 2, respectively (table 7).

The profit/cost ratio proved that the system was profitable. For every invested CUP in 2018, 2,12 CUP were earned, indicator that decreased in 2019, when 1,80 CUP/invested CUP were obtained.

Table 7. Economic indicators per year.

Indicator	year	
	1	2
	thousands of CUP/ha	
Net production income	4,56	3,51
Total production costs (fixed costs + variable costs)	2,15	1,95
Raw materials and supplies	0,65	0,49
Fuels	0,02	0,01
Energy	0,20	0,13
Salaries	0,63	0,72
Depreciation of active assets	0,17	0,12
Professional services	0,37	0,48
Gross profit	2,41	1,56
Profit/cost ratio	2,12	1,80

All the financial indicators had better performance in 2018, except total costs which, in spite of being higher, according to the graphic observation showed an approach (fig 5).

The results of this economic evaluation show the reasons why, for years, this scenario, as a good part of the Cuban productive systems, dairy or not, maintains a conventional management of the productions, since profitability is only valued in financial terms. The benefit/cost ratio showed that milk production was profitable. However, the energy evaluation showed the opposite result, since this methodology considered, in addition to the monetary expenses and income generated by economic materials, all the contributions made by nature and anthropogenic activities, which also represent expenses.

Complementing budgetary accounting with emergency accounting allows to evaluate the work of the biogeophysical system in agricultural systems and, therefore, to bring an integral evaluation of resources to the economic analysis. In doing so, it increases the total economic value of resources with a donor perspective, which enriches the economic analysis and fosters better informed, fully justified and sustainable economic decisions (Fonseca *et al*., 2019).

Energy analyses should not be considered an alternative to financial analyses, but a complement to better cover the complex interrelationships between finance and the environment in which food systems operate (Giampietro *et al*., 1994).

Conclusions

The energy indicators expressed the inability of the agroecosystem to sustain itself over time under a conventional production design. High energy costs (2,98 E+06 and 3,28 E+06 seJ/J), low support from renewable sources (33,82 and 38,47 %), adequate potential to produce primary energy (1,51 and 1,63) and high dependence on external resources (1,96 and 1,60) were recorded.

The classical economic analysis showed the profitability of the agroecosystem; while the energy synthesis evaluation showed that it is unsustainable, since this methodology considers, in addition to the monetary expenses and income, all the contributions made by nature, anthropogenic activities and economic materials.

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Conflict of interest

The authors declare that there is no conflict of interest.

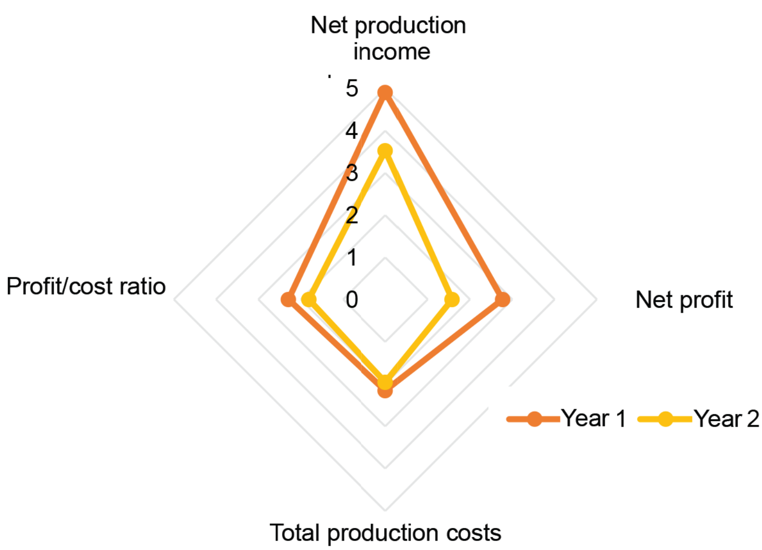

Fig. 5. Performance of economic indicators

Authors' contributions

- Jenifer Alvarez-Lima. Diagnosis, data collection, analysis and interpretation of information, formulation of objectives, establishment of working methods and preparation of the written document.
- Yanoy Morejón-Mesa. Data interpretation, formulation of objectives, establishment of working methods, writing and revision of the paper.
- José Carlos Oliva-Suárez, Diagnosis, data collection, analysis and interpretation of information, formulation of objectives, establishment of working methods and writing of the paper.
- Pedro Pablo del Pozo-Rodríguez. Data interpretation and revision of the paper.

Bibliographic references

Acosta, A.; Betancourt-Roche, J.; Bu-Wong, Á.; Fernández-Domínguez, P.; Mok-León, L.; Morales-Valiente, Claudia *et al. Estudio sobre la competitividad de la producción lechera cubana*. La Habana: INIE, IIPF, MINAG, FAO. https://www.researchgate.net/profile/Liu-Mok-Leon/publication/325498262_Estudio_de_competitividad_de_la_produccion_lechera_cubana/links/5b50ae2945851507a7b1baca/Estudio-de-competitividad-de-la-produccion-lechera-cubana.pdf, 2017.

Agostinho, F.; Oliveira, M. W.; Pulselli, F. M.; Almeida, C. M. V. B. & Giannetti, B. F. Emergy accounting as a support for a strategic planning towards a regional sustainable milk production. *Agric. Syst*. 176:102647, 2019. DOI: https://doi.org/10.1016/j.agsy.2019.102647.

Allegretti, G.; Talamini, E.; Schmidt, V.; Bogorni, P. C. & Ortega, E. El insecto como alimento: una evaluación emergente de la harina de insectos como fuente de proteína sostenible para la industria avícola brasileña. *Producción + Limpia*. 171:403-412, 2018.

Asgharipour, M. R.; Shahgholi, H.; Campbell, D. E.; Khamari, Issa & Ghadiri, A. Comparison of the sustainability of bean production systems based on emergy and economic analyses. *Environ. Monit. Assess*. 191 (1):1-32, 2018. DOI: https://doi.org/10.1007/s10661-018-7123-3.

Bassan, E. E.; Arcaro, I. & Ambrosio, L. A. Sustainability of milk production system: Capital diagnosis and emergy synthesis. Emergy synthesis 8. *Proceedings of the 8th Biennial Emergy Conference.* Gainesville, USA, 2015.

Brandt-Williams, S. L. & Fogelberg, S. C. L. Nested comparative emergy assessments using milk production as a case study. *3rd Biennial Emergy Research Conference.* Gainesville, USA: University of Florida. https://cep.ees.ufl.edu/emergy/conferences/index.shtml, 2004.

Carmenate-Figueredo, O.; Pupo-Feria, C. & Herrera-Toscano, J. A. Propuesta de acciones para la reconversión agroecológica de una finca en el municipio Las Tunas. *COODES*. 7 (2):264-274. http://scielo.sld.cu/pdf/cod/v7n2/2310-340X-cod-7-02-264.pdf, 2019.

Cavalett, O.; Queiroz, J. F. de & Ortega, E. Emergy assessment of integrated production systems of grains, pig and fish in small farms in the South Brazil. *Ecol. Modell*. 193 (3):205-224, 2006. DOI: https://doi.org/10.1016/j.ecolmodel.2005.07.023.

Cevallos-Suarez, M.; Urdaneta-Ortega, Fátima & Jaimes, E. Desarrollo de sistemas de producción agroecológica: Dimensiones e indicadores para su estudio. *Revista de Ciencias Sociales, Ve*. XXV (3):172-183. https://www.redalyc.org/journal/280/28060161012/html/, 2019.

Feitosa, E. O.; Lopes, F. B.; Andrade, Eunice M.; Palácio, Helba A. Q. & Bezerra, F. M. L. Sustainability of different production systems papaya (*Carica papaya* L.) and sorghum (*Sorghum bicolor* [L.] Moench) in the semi-arid region. *Chil. j. agric. res*. 79 (1):114-123, 2019. DOI: https://dx.doi.org/10.4067/S0718-58392019000100114.

Fonseca, A. M.; Marques, C.; Pinto-Correia, T.; Guiomar, N. & Campbell, D. Evaluación de emergencia para la toma de decisiones en sistemas agrícolas multifuncionales complejos. *Sistemas agrícolas*. 171:1-12, 2019.

Funes-Monzote, F. R. *Agricultura con futuro. La alternativa agroecológica para Cuba*. Matanzas, Cuba: EEPF Indio Hatuey, 2009.

Giampietro, M.; Bukkens, Sandra G. F. & Pimentel, D. Models of energy analysis to assess the performance of food systems. *Agric. Syst*. 45 (1):19-41, 1994. DOI: https://doi.org/10.1016/S0308-521X(94)90278-X.

López-Bastida, E. J.; García-Martínez, Yolanda & Valdés-López, A. Evaluación de la sostenibilidad de la producción de azúcar crudo mediante el análisis emergético. *Centro Azúcar*. 45 (2):59-67.http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2223-48612018000200006&lng=pt&tlng=es, 2018.

Maiolo, Silvia; Cristiano, S.; Gonella, F. & Pastres, R. Ecological sustainability of aquafeed: An emergy assessment of novel or underexploited ingredients. *J. Clean. Prod*. 294:126266, 2021. DOI: https://doi.org/10.1016/j.jclepro.2021.126266.

Nielsen, S. Reducciones en ecología y termodinámica. Sobre los problemas que surgen al trasladar el concepto de exergía a otros niveles jerárquicos y dominios. *Indicadores Ecológicos*. 100:118-134, 2019.

Odum, H. T. *Environmental accounting: emergy and environmental decision making*. New York: Wiley, 1995.

ONEI. *Anuario estadístico de Cuba 2019. Sector agropecuario indicadores seleccionados*. La Habana: Oficina Nacional de Estadística e Información. http://www.onei.gob.cu/sites/default/files/sector_agropecuario_enero_marzo_2019.pdf, 2020.

ONEI. *Anuario estadístico de Cuba 2020. Sector Externo*. La Habana: Oficina Nacional de Estadística e Información. http://www.onei.gob.cu/sites/default/files/08_sector_externo_2020.pdf, 2021.

Ortega, E.; Cavalett, O.; Bonifácio, R. & Watanabe, M. Brazilian soybean production: Emergy analysis with an expanded scope. *Bull. Sci. Technol. Soc*. 25 (4):323-334., 2005. DOI: https://doi.org/10.1177/0270467605278367.

Pozo-Rodríguez, P. P. del; Vallim-de Melo, C. & Ortega-Rodríguez, E. El análisis emergético como herramienta para evaluar la sustentabilidad en dos sistemas productivos. *Rev. Cie. Téc. Agr*. 23 (4):59-63. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2071-00542014000400010&lng=es&tlng=es, 2014.

Reinoso-Pérez, M.; Joseau, M. J. & Valdez, H. A. Alternativas para el manejo agroecológico de especies leñosas arbustivas en agroecosistemas ganaderos del noroeste de Córdoba, Argentina. *AgriScientia*. 36 (1):1-14, 2019. DOI: https://doi.org/10.31047/1668.298x.v36.n1.21966.

Santagata, R., Zucaro, A., Viglia, S., Ripa, M., Tian, X., Ulgiati, S. Evaluación de la sostenibilidad de los ecosistemas urbanos mediante indicadores de economía circular basados en emergencias. *Indicadores ecológicos*. 109:105859, 2020.

Suárez-Hernández, J.; Quevedo-Benkí, J. R.; Hernández-Aguilera, M. R.; Peña-Alfonso, A. & González-Telles, G. Procesos de innovación en la producción local de alimentos y energía en municipios cubanos. *Pastos y Forrajes*. 41 (4):237-242. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03942018000400001&lng=pt&tlng=es, 2018.

Wada, D. K. & Ortega, E. Comparação dos balanços de emergia de dois sistemas de produção de leite. En: E. Ortega, ed. *Engenharia ecológica e agricultura sustentável: Exemplos de uso da metodologia emergética-ecossistêmica*. Campinas, Brazil: LEIA-FEA-UNICAMP, 2003.