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Electricity Production from Agricultural Wastes: An Emergy Evaluation

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ABSTRACT

A proper waste management policy should be based on necessary reclamation of refuses, which are not only regarded as something to throw out but rather as a potential resource. This approach requires the knowledge and the use of the available technologies. In this context, the electricity production from the agricultural sector residues has been widely investigated in order to point out the potential benefits of greenhouse gas emission reduction and energy recovery by waste reclamation. In this paper, three systems were evaluated to assess the sustainability and the efficiency of each option. The first system uses the waste of a sugar cane ethanol plant that generates 7.17 GWh/year. The second system uses pig farming waste, generating 8.63 GWh/year, and the third uses waste from cattle that produce 11.80 GWh/year. Transformities calculated have shown that the electricity production from cattle residues is more efficient than that produced with the use of sugar cane or pig farming wastes. Indices and indicators of efficiency, effectiveness and environmental loading were calculated to compare the strengths and weaknesses of each system.

INTRODUCTION

The accelerated degradation of the rural environment results in a responsibility for developing agricultural systems that preserve the environment and the use of resources properly. Agricultural wastes are diverse and include wood residues, organic wastes, crops residues, and animal wastes. However, the use of crop residues and manure to obtain electricity is still remarkably rare. On the other hand, the imminent need to diversify the energy matrix leads to search for solutions that involve the use of agricultural wastes to generate electricity. Electricity supply is essential to prosperity, and to economic and social development, and its production from agricultural wastes may reduce the pressure caused by the demand for electricity in rural areas.

Emergy synthesis is used to quantify environmental costs (Brown and McClahan, 1996), as it assesses all the inputs that supply a system, and especially those that are usually neglected by classic economic accounting methods.

The present study comprehensively evaluates resources utilization for technologies using agricultural wastes to produce electricity that include (a) sugarcane residues, (b) cattle manure, and (c) pig manure. Emergy indicators, such as percent renewable (%R), emergy yield ratio (EYR), environmental load ratio (ELR) and environmental sustainability index (ESI), are used to evaluate the environmental load and local sustainability of the electricity production.

The emergy analysis starts with the design of energy diagrams (Odum, 1996). The study of the diagrams makes it possible to identify the boundaries established for the studied systems and its main components and also the interactions between them. On the diagrams all the flows of material, energy and services necessary for the operation of the system are identified. For the emergy analysis a line is created and it crosses the boundaries of the systems; it represents a flow.

Among the papers in the literature using the flows of emergy accounting for assessing the bio-systems capable of generating energy, we can mention: Björklund et al (2001), estimated the transformity of electricity generated by harnessing the biogas produced by a digester installed on the workstation sewage treatment system with conventional treatment (WWTP, Waste Water Treatment Plant), Sweden. Comparing the value obtained with the transformity of the electricity used in the system, which consists of a portion of energy from nuclear and hydroelectric power from elsewhere, concluded that if the system were used to generate electricity, would be ineffective because the transformity found $3.10x10^5$ sej/J was higher than the other sources available in your country, that for hydroelectricity was $8.0x10^4$ sej/J (solar emergy joules per joule). Law and Wang (2008) performed the calculation of transformity for electricity generation from municipal waste and found the value of $7.61x10^6$ sej/J for energy generated from an incinerator. Ometto et al, 2006 calculate the transformity in his work for alcohol, electricity and food for a Small Alcohol Integrated Plant (Corsini, 1992), obtaining the transformity of electricity $1.46x10^5$ sej /J.

The Electricity Generation from Renewable Sources

In the present study we assume, according to Braga et al. (2002), that renewable resources are the natural resources still available after being used , which happens due to the natural cycles. So, the renovation rate is higher than the use rate of these resources.

Renewable sources provide energy vectors: hydraulic energy, biomass, animal traction and human force, for example.

Nowadays, sustainable development is seen as a global need so that the future generations have conditions to survive (Brundtland, 1987). With the creation of the Kyoto Protocol, in 1992 (MRE, 1997) it was established that the developed country should reduce the emissions of greenhouse gases in the period from 2008 to 2012. Developing countries, as Brazil, although exempt from this commitment, shall follow the principle of common responsibility, because the global warming is an issue that concerns to every nation.

METHODOLOGY

The emergy (energetic memory) is used as a tool of the present study based on the concepts presented by Odum (1996). The total value for emergy includes all the resources and services used for obtaining a product, process or service, whether they come from the environment or from the economy. For analysis, some energy diagrams are designed to identify all the material and energy flows that make the system. This methodology uses its own algebra, with which it is possible calculate indexes from the relations between the resources that make the studied system. The emergy is measured in joules of solar emergy, which makes it possible to account the flows from the environment and the economy on a common basis, the sej (solar emergy joules). The transformity, sej/J, defines the quantity of emergy (sej) that is need for obtaining one joule of a product, process or service, whether it's natural or anthropogenic. Once we define the transformity of a product, it's possible to calculate the direct and indirect solar energy necessary for its obtainment.

SYSTEMS DESCRIPTION

The sugar cane plant discussed in this text was studied by Ometto et al (2006). With an area of 4,360 ha, where 1494 ha are assigned to the sugarcane plantation, it produces daily 40,000 liters of ethanol and 0.271 MWh of electricity per ton of sugarcane, using a 67 bar/480oC boiler that operates 210 days per year. In the original study (Ometto et al, 2006) the plant is integrated to production of cattle, and in this study, a partition of the consumables was made. The cattle system, separated from the sugar cane plantation, uses 180 ha. The herd has 3,438 animals that produce 947 tons of meat, 5,668 liters of milk and 1,18x104 MWh of electricity per year. Pigs production assessment is based on the study of Cavalett (2004), adapted for 5,400 pigs, producing 378 tons of meat and $8.63x10^3$ MWh of electricity per year.

Data for the emergy accounting of the ethanol and cattle plants were taken from Ometto et al, 2006. Data for pig production were adapted from Cavalett, 2004. Transformities and emergies per mass used in this work were taken from literature (Table 1). The income flows of each effluent treatment system were classified into three categories: R, N and F, showed separately on the tables considering two steps: (i) construction phase and (ii) operation phase.

EMERGY ANALYSIS

The data necessary for the emergy accounting of the alcohol and cattle plant were obtained on the article made by Ometto et al, 2006 and for the pigs the data are from Cavalett, 2004. The transformities and emergies per mass used in this work are from the literature (Table 1).

Indicators

The indicators used in the present study were developed by Odum (1996): the emergy yield ratio (EYR), the emergy investment ratio (EIR), the environment load ratio (ELR). Beyond these indicators, the environmental sustainability index was also calculated (ESI). The ESI, proposed by Ulgiati and Brown (1998), presents the ratio between EYR and ELR. The percentage of renewable emergy (%R) is also used for the comparison between the systems of energy generation.

Table 1. Transformity and emergies per unit used in this work.

Item	Emergy per unit	Unit	References
Sun	1.00	sej/J	By definition
Wind	$2.45x10^3$	sej/J	Odum, 2000
Rain (potential)	$1.82x10^4$	sej/J	Ometto et al, 2006
Fuel	$5.50x10^4$	sej/J	Bastiyearni et al., 2001
Soil loss	$7.38x10^4$	sej/J	Ometto et al, 2006
Water from aquifer	$1.10x10^5$	sej/J	Ometto et al, 2006
Water	$1.76x10^5$	sej/J	Odum, 2000
Pigs	$9.21x10^5$	sej/J	Cavalett, 2004
Cattle	$1.73x10^6$	sej/J	Ometto et al, 2006
Labor	$4.30x10^6$	sej/J	Silva, 2006
Corn	$9.25x10^8$	sej/g	Ortega, 2003
Seeding	$1.47x10^9$	sej/g	Ometto et al, 2006
Pesticides	$1.48x10^9$	sej/g	Ometto et al, 2006
Nutrients	$3.00x10^9$	sej/g	Ometto et al, 2006
Nitrogen	$4.61x10^9$	sej/g	Ometto et al, 2006
Pig’s food	$6.08x10^9$	sej/g	Cavalett, 2004
Fertilizer	$3.80x10^{12}$	sej/g	Ometto et al, 2006
Bran	$3.26x10^{12}$	sej/g	Cavalett, 2004
Additional services	$3.70x10^{12}$	sej/$	Coelho et al, 2002
Fertilizer	$3.80x10^{12}$	sej/g	Ometto et al, 2006
Steel	$1.80x10^{15}$	sej/g	Ometto et al, 2006

In this research, all the materials, equipment and labor used for the construction and operation phases were accounted. The income flows of each effluent treatment system were classified into three categories: R, N and F, shower separately on the tables considering two steps: (i) implementation phase and (ii) operation phase. Emergy indicators were used for the comparison of the systems.

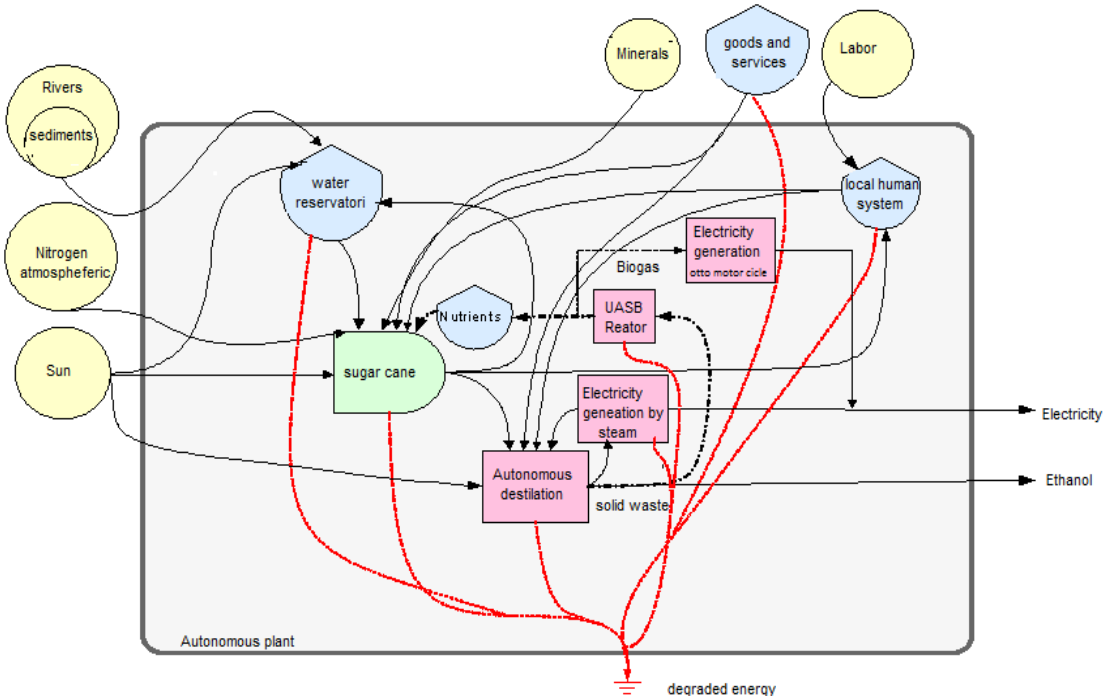

Figure 1. *Energy diagram of the autonomous system of the plant (adapted from Ometto et al, 2006).*

Results of the Emergy Analysis

Autonomous plant system

The autonomous plant system's energy diagram is shown on Figure 1, where we can see all the energy flows that make the system and the interactions with the environment. It was adapted from the work of Ometto et al, 2006, and so are the money exchanges with the market, the taxes and the cattle; a system of electricity generation using an Otto motor cycle was included. The Table 2 presents the material and energy flows participating in Plant Autonomous System.

Emergy analysis

The total emergy of the autonomous plant system is 5.63×10^{18} sej/year. Approximately 8% sej/sej of local non renewable resources is used, 32% sej/sej is renewable resources and 60% sej/sej of the resources is from the economy. The system uses about 33.4% sej/sej of its total emergy on the implementation and 66.7% during its operation.

The functional unit adopted was 1GWh of electricity. The production of extra electricity per year on the plant is 7.17 GWh, the emergy per unit is 7.86×10^{17} sej/GWh and the transformity is 2.18×10^{5} sej/J.

Cattle system

The cattle system's energy diagram is shown on Figure 2, where it is possible noticing all the energy flows that make the system and the interactions with the environment. It was adapted from the work of Ometto et al, 2006, and so are the money exchanges with the market, the taxes and the cattle; a system of electricity generation using an Otto motor cycle was included. Table 3 presents the material flows and energy to participate in the system of cattle.

Table 2. Emergy Evaluation of the autonomous plant system (*).

Notes	Description	Unit	Class	Value (un/year)	Emergy per unit (sej/un)	Emergy (sej/year)	% (sej/sej)
	Implementation Phase						
1	Seeding	g/year	R	$4.30x10^{7}$	$1.47x10^{9}$	$6.32x10^{16}$	1%
2	Soil loss	J/year	N	$6.15x10^{12}$	$7.38x10^{4}$	$4.54x10^{17}$	8%
3	Equip. and structure	$/year	F	$2.64x10^{5}$	$3.70x10^{12}$	$9.76x10^{17}$	17%
4	Steel for reactors & UASB filters	g/year	F	$9.43x10^{4}$	$1.80x10^{9}$	$1.70x10^{14}$	<1%
5	Labor	J/year	F	$9.63x10^{10}$	$4.30x10^{6}$	$4.14x10^{17}$	7,0%
	Operation phase						
6	Precipitation	J/year	R	$8.86x10^{13}$	$1.82x10^{4}$	$1.61x10^{18}$	29%
7	Nutritents	g/year	R	$2.69x10^{7}$	$3.00x10^{9}$	$8.07x10^{16}$	1%
8	Nitrogen (atm)	J/year	R	1.05x107	$4.61x10^{9}$	$4.82x10^{16}$	<1%
9	Water from aquifer	J/year	R	$3.69x10^{9}$	$1.10x10^{5}$	$4.06x10^{14}$	<1%
10	Fertilizer	g/year	F	$4.88x10^{7}$	$3.80x10^{9}$	$1.86x10^{17}$	3%
11	Pesticides	g/year	F	$3.59x10^{6}$	$1.48x10^{9}$	$5.31x10^{15}$	<1%
12	Labor	J/year	F	$3.66x10^{11}$	$4.30x10^{6}$	$1.58x10^{18}$	28%
13	Agricultural operations	$/year	F	$1.10x10^{4}$	$3.70x10^{12}$	$4.08x10^{16}$	1%
14	Maintenance	$/year	F	$4.85x10^{4}$	$3.70x10^{12}$	$1.79x10^{17}$	3%
	Total Emergy					$5.63x10^{18}$	100,0%

(*) Detailed calculations available from authors.

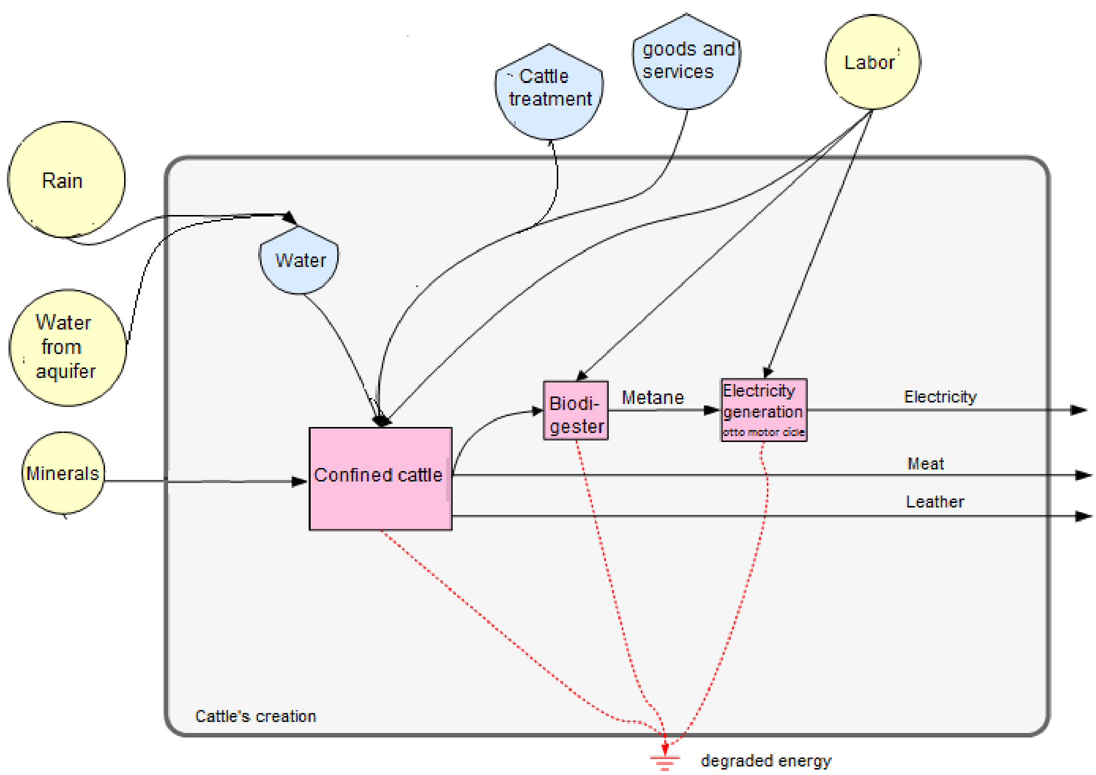

Figure 2*. Energy diagram of the system of cattle.*

Table 3. Evaluation of the emerging system of cattle (*).

Note	Description	Unit	Class	Value (un/year)	Emergy unit (sej/un)	Emergy (sej/year)	% (sej/sej)
	Implantation phase						
2	Cattle	J/year	R	$6.39x10^{10}$	$1.73x10^{6}$	$1.11x10^{17}$	5%
3	Soil Loss	J/year	N	$7.41x10^{12}$	$7.38x10^{4}$	$5.47x10^{17}$	27%
7	Cattle shed	$/year	F	$2.92x10^{3}$	$3.70x10^{12}$	$1.08x10^{16}$	1%
8	Ditches	$/year	F	$1.33x10^{3}$	$3.70x10^{12}$	$4.92x10^{15}$	<1%
9	Biodigester	$/year	F	$1.00x10^{3}$	$3.70x10^{12}$	$3.7x10^{15}$	<1%
	Operation phase						
10	Rain (potential)	J/year	R	$1.07x10^{13}$	$1.82x10^{4}$	$1.95x10^{17}$	10%
11	Nutrients	g/year	R	$3.24x10^{4}$	$3.00x10^{9}$	$9.72x10^{13}$	<1%
12	Nitrogen	J/year	R	$1.26x10^{4}$	$4.61x10^{9}$	$5.81x10^{13}$	<1%
13	Water of aquifer	J/year	R	$4.45x10^{8}$	$1.10x10^{5}$	$4.9x10^{13}$	<1%
14	Labor	J/year	F	$9.17x10^{10}$	$4.30x10^{6}$	$3.94x10^{17}$	19%
15	Cattle treatment	$/year	F	$1.87x10^{5}$	$3.70x10^{12}$	$6.92x10^{17}$	34%
16	Maintenance	$/year	F	$1.98x10^{4}$	$3.70x10^{12}$	$7.33x10^{16}$	4%
	Total emergy					$2.03x10^{18}$	100%

(*) Detailed calculations with authors.

Emergy analysis

The total emergy of the cattle system is $2.03x10^{18}$sej/year. Approximately 27% sej/sej of non renewable resources is used, 15% sej/sej is renewable resources and 58% sej/sej of the resources is from the economy. The system uses about 33% sej/sej of its total emergy on the implementation and 67% during its operation.

The functional unit adopted was 1GWh of electricity. The production of extra electricity per year on the plant is 11.8 GWh, the emergy per unit is $1.72x10^{17}$ sej/GWh and the transformity is $4.77x10^{4}$ sej/J.

Pigs system

The pigs system's energy diagram is shown on Figure 3, where we can see all the energy flows that make the system and the interactions with the environment. It was adapted from the work of Ometto et al, 2006, and so are the money exchanges with the market, the taxes and the pigs; a system of electricity generation using an Otto motor cycle was included. Table 4 presents the material flows and energy to participate in the system of pig rearing.

Emergy analysis

The total emergy of the pigs system is $3.40x10^{18}$ sej/year. Approximately 15% sej/sej of non renewable resources is used, 6% sej/sej is renewable resources and 78% sej/sej of the resources is from the economy. The system uses about 9% sej/sej of its total emergy on the implementation and 90% during its operation.

Wastes from agricultural systems can be converted in electricity on a series of energy transformations (Figure 4). The functional unit adopted was joule of electricity. The production of extra electricity per year on the plant is 9.63 GWh, the emergy per unit is $3.93x10^{17}$ sej/GWh and the transformity is $1.09x10^{5}$ sej/J.

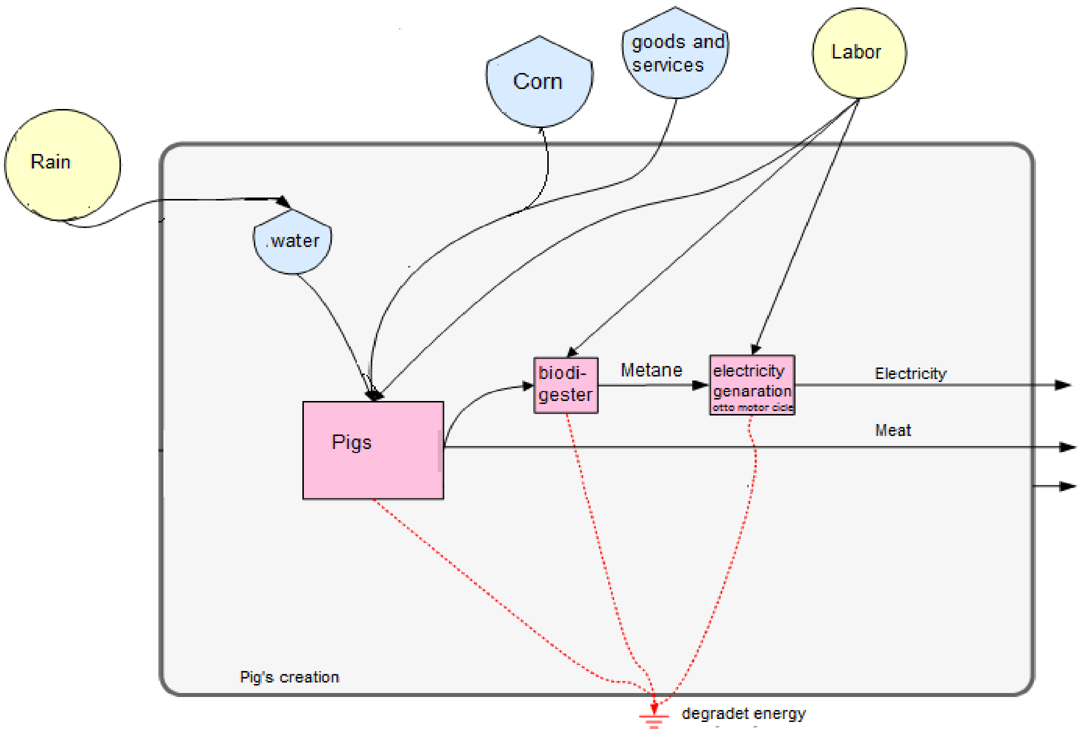

Figure 3. *Energy diagram of the system of pig rearing.*

Table 4. Emergy evaluation of pigs (*).

Note	Description	Unit	Class	Value /(un/year)	Emergy per unit (sej/un)	Emergy /(sej/year)	% /(sej/sej)
	Implementation phase						
1	Pigs	J/year	R	$8.14x10^{10}$	$2.51x10^{4}$	$2.04x10^{15}$	<1%
2	Soil loss	J/year	N	$3.70x10^{12}$	$7.38x10^{4}$	$2.73x10^{17}$	8%
3	Pig farm	$/year	F	$9.25x10^{3}$	$3.70x10^{12}$	$3.42x10^{16}$	1%
4	Equipments of pig farm	$/year	F	$3.60x10^{2}$	$3.70x10^{12}$	$1.33x10^{15}$	<1%
5	Biodigester	$/year	F	$1.00x10^{3}$	$3.70x10^{12}$	$3.70x10^{15}$	<1%
	Operation phase						
6	Rain (Potential)	J/year	R	$5.34x10^{12}$	$1.82x10^{4}$	$9.72x10^{16}$	3%
7	Corn 12.1%	g/year	R	$1.26x10^{8}$	$7.69x10^{8}$	$9.69x10^{16}$	3%
8	Corn 35.3%	g/year	N	$3.29x10^{8}$	$7.69x10^{8}$	$2.53x10^{17}$	7%
9	Corn 52.6%	g/year	F	$5.48x10^{8}$	$7.69x10^{8}$	$4.21x10^{17}$	12%
10	Soy bran	g/year	F	$3.86x10^{8}$	$3.26x10^{9}$	$1.26x10^{18}$	37%
11	Pig's food	g/year	F	$5.94x10^{7}$	$6.08x10^{9}$	$3.61x10^{17}$	11%
12	Fuel	J/year	F	$1.43x10^{9}$	$5.50x10^{4}$	$7.87x10^{13}$	<1%
13	Labor	J/year	F	1.3810^{11}	$4.30x10^{6}$	$5.94x10^{17}$	17%
	Total emergy					$3.40x10^{18}$	100%

(*) Detailed calculations with the author.

Comparison among the transformities of the studied systems

The Table 5 presents the comparison between the emergies per unit and generated energy of the studied systems. The values found in emergy per unit presented on Table 5 indicate that the cattle system is the one that uses the lowest amount of resources to produce electricity. The pigs system is 2.28 times bigger and the system with the highest emergy per unit is the autonomous plant's system with a percentage that is 4.57 times bigger than the cattle system. The value of the emergy per unit is an efficiency index and makes it possible to reckon that the cattle system is more efficient on the electricity generation when we refer to the use of resources.

Observing the results on Table 5 for the transformity of electricity generated in these systems, it's noticeable that the transformities of the systems have values that are very close and the value for the autonomous plant is similar to the one determined by Odum (1996), that is $2.00 x 10^5$ sej/J.

This analysis doesn't mean that the systems have the same performance when compared to other products, as this concern only about electricity generation.

Evaluation of the Energy Generation Ways and its Transformities

Wastes from agricultural systems can be converted in electricity on a series of energy transformations. Figure 4 presents the transformations studied in this work. The values on Figure 4 were attributed from the arbitrary normalization of electricity generation for each system, calculating the emergy flows involved in the processes.

Table 5. Comparison between the emergies per unit and energy generation of the studied systems

System	Generated energy GWh	Emergy per unit sej/GWh	Transformity sej/J
Autonomous plant	7.17	$7.86 x 10^{17}$	$2.18 x 10^5$
Cattle	11.8	$1.72 x 0^{17}$	$4.77 x 10^4$
Pigs	8.63	$3.93 x 10^{17}$	$1.09 x 10^5$

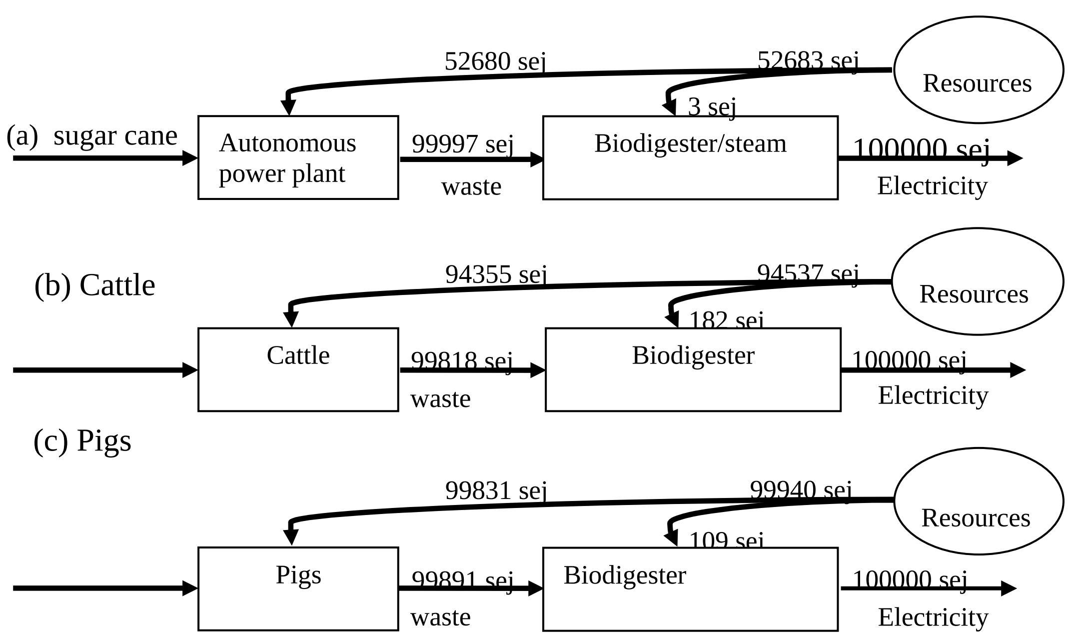

Figure 4. *Emergy Flows for the production of electricity (a) Autonomous Power Plant, (b) Cattle, (c) Creation of Pigs.*

Indicator Results

As we can see on Table 2, 3 and 4 the total emergy is made of 3 types of resources: R, N and F, from which it is possible to calculate the indicators in emergy (Odum, 1996), as the Table 6 presents. According to the EYR index (Table 6), we verify that the cattle system presents the best income in emergy because it uses a bigger proportion of local renewable and non renewable resources (R+N) when compared to the financial investment. The EIR index (Table 6) indicates that the cattle system presents to be the most competitive. The investment of resources from the economy when compared to the natural resources used on the autonomous plant is smaller.

The environment load ratio ELR (Table 6) evaluates the environmental stress, and the lower this index, the lower is the stress imposed to the environment (Brown and Ulgiati, 2002). It's noticeable that the result obtained by the autonomous plans system (2.12) represents that the solar energy of the non renewable resources and those from the economic system is 2.12 times bigger than the equivalent solar energy of the renewable resources that were used, and it indicates a low environmental load, that is 2.66 times lower than the cattle system and 7.7 times lower than the system of the pigs, showing to be the system with the lower environmental stress.

The sustainability index ESI (Table 6) defined for the systems indicate the necessity for improvement, so to increase the sustainability of the cycles. Comparing these values, the autonomous plant's index showed to be 2.63 bigger than the value for cattle and 9.87 times bigger than the index for pigs; thus, the autonomous system is sustainable for a longer period of time.

The index of renewable emergy %R (Table 6) indicates the rate of renewable energy involved on the process. According to the Kyoto Protocol (MRE, 1997), that established that until 2010 the use of renewable energy sources should reach 10% of the energy matrix (Braga et al, 2002), we verify in this study that only the pigs system didn't reach this index. It is important to say that the system of the autonomous plant presents the biggest rate, with 32% the renewable energy on its productive chain of its energy flows.

The comparison of the indexes values found for the systems indicate that the electricity generation of the autonomous plant offers lower impact to the environment that the compared biosystems. Although the complete system uses a lower amount of resources (transformity) to generate the same quantity of electricity, this system uses mainly resources that come from the economy (Table 6). The distribution of the flows on the autonomous plant system (Table 6) between R, N and F shows better use of the local and free resources on this system, what reflects on the values of the calculated indexes.

CONCLUSIONS

According to the results, we verify that the Autonomous Plant's indexes show the best results, but these values are very close and are not enough to define the system with the best performance.

The emergy analysis allows us to make a comparison of the transformity (intensity of the flows). The studied systems present transformity values also very close for the electricity generation, and the transformity for the autonomous plant system is approximately 4.5 times bigger than the value for the cattle system and 2 times bigger the pig's system. We believe it is due to the fact that the Autonomous Plant system uses a bigger quantity of resources because of its technology's complexity. Analyzing the transformity, the system with the best performance is the cattle system

Table 6. Summary of the indexes in emergy.

Indexes in emergy	Autonomous plant	Cattle	Pigs
Emergy Yield Ratio (EYR)	1.67	1.72	1.27
Emergy Investment Ratio (EIR)	1.50	1.38	3.70
Environmental Load Ratio (ELR)	2.12	5.64	16.31
Environmental Sustentabilidade Index (ESI)	0.79	0.30	0.08
Percentage of Renewable Energy (%R)	32.02	15.07	5.76

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