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ENVIRONMENTAL ASSESSMENT OF RURAL HOUSING WITH THE eMERGY METHOD

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— Abstract—

This paper presents the main characteristics of three types of rural housing (considering its materials and its structural typology), from municipality of Yajalón (Chiapas), and its environmental assessment is carried out, through an emergetic analysis of inputs. A total of 30 field visits were carried out in order to gather the necessary information to carry out this study. In addition to this information, the catalog of construction concepts and maintenance and operation costs were used to obtain, through the eMergy, corresponding emergetic indices and in this way the sustainability of these houses was determined.

Keywords

Environmental assessment; renewable resources; non-renewable resources; energy form; transformity.

The constant current deterioration of the environment forces us to take into account the environmental aspect in almost all the activities that are carried out. And it is in the construction area where more attention must be paid, because this activity is what causes more radical changes in the original environment.

Housing can be erected in the countryside in isolation or integrated to small base settlements; it can also be built in significant population centers. In the first case it is called rural housing, in the second, urban housing.

Rural dwellings tend to be independent, unconnected constructions, or only weakly linked by roads, with a rudimentary grouping arrangement that does not impede an individual equilibrium with the environment. Most of them lack water supply, solid and liquid waste disposal systems, electricity and telephony.

Rural dwellings have energy inputs that can be renewable, non-renewable and flows acquired or imported. These inputs, in turn, affect the environment. Consequently, it is necessary to study the sustainability of these homes, through a methodology capable of integrating environmental, economic and social indicators. Such methodology of environmental evaluation is *eMergy*.

eMergy is the sum of all energy inputs, directly or indirectly, necessary for a process to provide a specific product or service, when the inputs are expressed in the same form or type of energy, usually solar energy.

In the last 30 years, this technique has shown a great capacity to evaluate the sustainability of rural and urban housing. It basically consists in measuring the quality of the different forms of energy that have been used, directly or indirectly, in the transformations necessary to generate a product or service.

Technically, eMergy is defined as the amount of solar energy to produce a product; its unit is the solar *joule* (seJ). Although the energy is conserved according to the first law of thermodynamics, according to the second law, the capacity of the energy to perform a job is exhausted and cannot be reused. By definition, solar eMergy is only conserved in a chain of transformations until the capacity to carry out work of the remaining final energy is exhausted (generally in interactive feedback). This series of transformations make it necessary to go to the concept of *Transformity*, which is the amount of direct or indirect energy required to produce per unit of useful energy (10,000 seJ/J wood, for example). In other words, it is the measure of energy that is required to transform one type of energy into another. Establish the ecological hierarchy in an energy analysis.

Emergetic analyzes include environmental, social and economic variables and indexes are calculated as comparison tools for different systems.

Because the eMergy is able to evaluate the systems' energy flows, in such a way that the environmental and financial aspects of the systems can be compared, in this work an environmental assessment of three types of rural housing is made, through an analysis emergetic by inputs. The amounts of natural resources, of non-natural resources, of materials (or external sources) and of services are calculated. These factors are multiplied by the transformability of each input, to obtain the total eMergy or transformation of the homes under study; finally the emergetic indexes of the dwellings are obtained.

BACKGROUND

Rural areas of developing countries are economically depressed in relation to urban centers. This translates into a migration trend. The patterns of growth, life expectancy and the birth rate cannot be assumed by the economy of the smallholding. The main cause is found in economic factors. The industrial development and with it the demand of labor force, has originated the migration of the rural population as an alternative to the precariousness of the agrarian economy.

In rural areas, the distances between suppliers and consumers are large, so transportation takes more time. Low population densities, in turn, make the conduct of business for retail consumption less efficient. The prices of goods and land (except in rich agricultural areas) tend to be lower, but the cost of construction and transportation is higher.

Frequently, the rural environment depends on the price fluctuations of its products. Economy tends to be seasonal. Infrastructure is relatively poor because investment is less productive in low-density settlements. In addition, rural societies tend to be conservative and traditional, although the development of communications has reduced isolation.

In the studied rural environment (Yajalón, Chiapas) most of the houses are built by means of self-construction, with inadequate materials or little resistant, without attending to a regulation and without technical advice. Normally, these houses lack drinking water networks, sanitary drainage and electric power networks. Its floor is of dirt and overcrowding is common.

These homes are located in a space known as *solar* whose dimensions vary between 1000 and 1500 m^2. Frequently, this land has a wide variety of fruit, ornamental and aromatic plants which in addition to providing fruits and diverse products for the family provide shade to the inhabitants of the house. It is usual to raise poultry and domestic pigs. It is customary to have them loose on the site, and even inside the house.

It is usual that the building has no windows, or that the windows are closed with wood or cloth. The first houses were made with materials from the region (palm roofs, wood and *bajareque*). However, the palm roofs accumulated many animals and pests that affect the health of the family and had a short duration. They were replaced with galvanized sheet roofs for longer duration and protection from the rain. Little by little, the earth walls were replaced by wood, as it is a material more accessible and easy to work (see Image 1).

Image 1. Typical rural housing in Yajalón (Chiapas), with wooden walls and a sheet roof.

With the entry of support programs for housing improvement, by the government, the indiscriminate use of the concrete block began, without generating an adequate housing model. Thus arose the model prototype called the new millennium model, whose walls and ceilings are all made of galvanized sheet, and are generally the product of surplus donations of sheets that frequently reach communities (see Image 2).

Image 2. Typical rural housing of Yajalón (Chiapas), with concrete block walls and sheet roof.

In many cases the house consists of a single space of 30 to 40 m², in which 1 or 2 beds are located for the whole family, from 7 to 10 people. In other cases there is a division in between, to form 2 rooms, in order to separate the bedrooms of parents and children.

This rural house, presents unfavorable conditions of habitability. The bedrooms lack internal divisions and furniture to accommodate clothes and belongings, there is unhealthiness due to excess humidity and pests of insects and animals. In addition there is no privacy inside, parents and children spaces are mixed.

In general, the kitchen is a space separated from the room, in many cases it is a small, improvised construction, and that it does not have adequate place for its utensils. The floor is of soil and since there are no windows, it does not have lighting or ventilation.

Inside the kitchen, the stove is an important piece. It usually has a wooden base, is open and only uses a metal tripod on which the pots are placed. It is an instrument that spends too much firewood, and also generates a lot of heat and smoke pollution (see Image 3).

Figure 3. Representative stove of a typical rural housing in Yajalón (Chiapas).

Figure 4. Representative latrine of a typical rural housing in Yajalón (Chiapas).

The latrine constitutes a critical point in rural housing (see Image 4). It often lacks an adequate well for waste, and is a source of disease, of mosquitoes and rodents, of odors and dirt. Worst case scenario, the communities do their physical needs in the open air, which constitutes a source of contamination and spread of diseases.

These conditions cause great impacts on the diversity and natural potential of the area, leading to its exploitation and degradation. Therefore, the need for rural development to face these problems is stressed, which not only affect its inhabitants but the whole environment. It is vital, therefore, to improve the environmental and energy performance of rural homes if sustainable development is to be achieved.

Environmental protection has different meanings in rural areas. If it favors the advantages of its inhabitants, it will be favorably received. If it is perceived as a threat to the community by changing agricultural practices, subtracting resources from its economic use or interference with construction or infrastructure development, it will not be favored.

However, as it was already mentioned, many of the rural settlements lack infrastructure, services and equipment systems that provide them with an adequate quality of life. In this sense, it is necessary to measure and assess the quality of life or environmental quality of rural settlements, to improve the physical conditions of the built environment and its inhabitants.

METHODOLOGY

In this work, the environmental accounting methodology called eMergy is used to evaluate the sustainability of three types of rural housing in Chiapas. This is a biophysical method, developed by Odum (1996), and is based on the analysis of energy with memory, in order to carry out in a correct way the accounting of the services provided by ecosystems free of charge. EMergy is thus the sum of all the energy of a form, necessary to develop a flow of energy in another way, in a given period of time. This tool is used to compare the work of nature with that of humans on a fair and equitable basis. It has the capacity to represent, at the same time, the contributions of nature and economy in a single unit and criterion, providing a diagnosis of comparative evaluation, among the different results of environmental performance over time (Guarnetti *et al*, 2006).

The eMergy analysis is designed to evaluate the systems' energy and material flows in common units (joule solar, seJ) that allow the analyst to compare environmental and financial aspects of the systems (Guillén Trujillo, 1998).

Three different energy inputs are recognized: renewable locals, non-renewable locals and flows acquired or imported. Thanks to the division of the energy inputs of the community in these terms, it is possible to make several very enlightening calculations: the environmental load rate of the population, its rate of energy efficiency and, what is more important, and its sustainability index. In the emergetic analyzes, environmental, social and economic variables are included and indexes are calculated as comparison tools for different systems. In this work, emergetic and financial indexes are calculated to determine the sustainability in the construction of the proposed homes.

The following characteristic activities of an emergetic study were carried out:

1. Definition of the space-temporal limits of the system investigated.
2. Data gathering in the field, for each dwelling, with the purpose of determining the physical quantities of renewable, non-renewable resources, materials and services that are part of the system studied.
3. Modeling of the system, by flow charts about matter and energy, using the energy symbology (Odum, 1994), of the interaction between the external and internal sources of the system, and the natural and anthropic productive systems, as well as the outflows of the system and the feedback of it.
4. Simplification of the models to capture the main inputs and outputs to the system, as well as other flows that explain the internal operation of it. The system's main flows were considered: R (renewable eMergy flow), N (local non-renewable eMergy flow), M (materials and tools), S (services and labor) and Y (eMergy used by the system).
5. Construction of a table with the main flows of eMergy.
6. Calculation of emergetic indexes.

Since this study analyzes the sustainability of three houses, with common characteristics, three separate phases were evaluated: construction, maintenance and operation. For the construction phase, the volumes of work were calculated and the analysis of unit prices was carried out. This allows to quantify the materials used in the construction of each house.

Regarding the maintenance and operation stages, the database was integrated through 30 field surveys carried out among the inhabitants of Arroyo Carrizal, municipality of Yajalón (Chiapas). These surveys gathered information on the homes' physical and economic conditions, as well as data on the operation and maintenance costs (Cruz Vázquez, 2015).

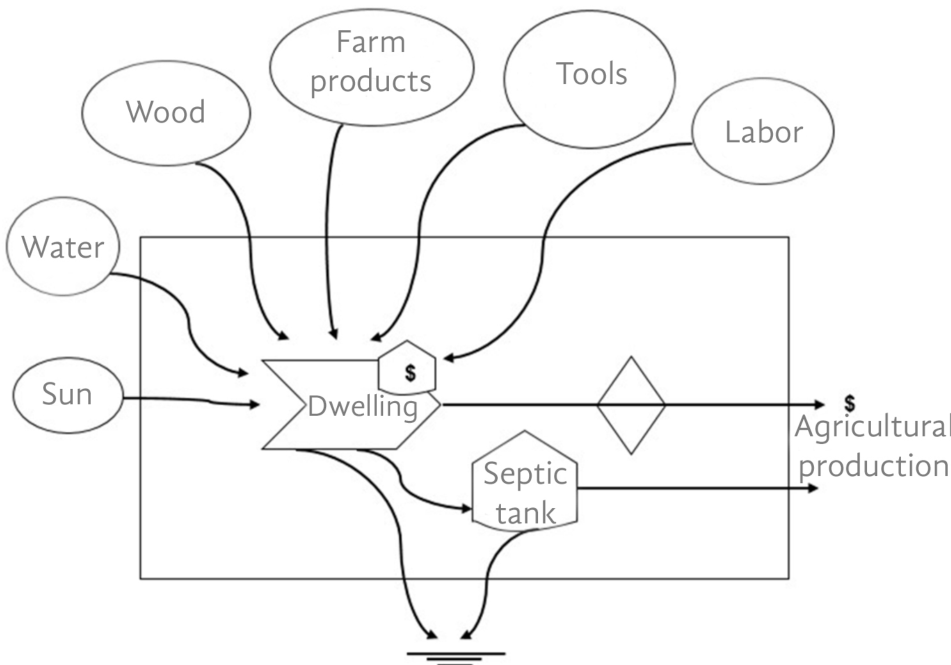
The environmental assessment of the houses was made considering the environmental setting in which they are located, the main resources and building materials. Natural resources, non-natural resources and external sources were identified, and their transformation was used.

The latter, the transformability, is the amount of eMergy introduced to the system per unit of useful energy generated. For example, if 10000 solar emjoules are required to generate a joule of wood, then the solar transformation of the wood will be 10,000 solar emjoules per joule (seJ/J, in its abbreviated form). By definition, the transformability of sunlight absorbed by the Earth is 1.0.

The quantities of each of the resources were quantified and finally, these quantities were multiplied by the transformation to obtain solar eMergy.

The modeling of the system, considering the flow of matter and energy, for the dwellings studied, is summarized in Image 5. This diagram shows the sources external to the system (sun, rain, labor, etc.), the interaction of the dwelling with these external sources, the interaction between what the system produces and the economy, and the unusable output of the system.

Image 5. Rural housing energy flow chart.



RESULTS AND DISCUSSION

The lot where the rural house 1 is located, has a total area of 476 m², consists of two independent buildings. One building serves as a kitchen and dining room, and another is used as a bedroom. Both buildings have rammed earth floor, walls and doors of pine wood of the region and metal sheet roof. There is also a bathroom on the outside, without a storage tank, concrete block walls, blacksmith's door and sheet metal roof and a septic tank where all the waste from the bathroom is received. In Image 6, rural housing 1 is shown.

The land where the rural house 2, has a total area of 688 m², is made up of two independent buildings. One of them works as a room, with walls of pine planks of the region, doors and windows of the same material as the walls, metal sheet roof and concrete floor. The other building is used as a kitchen, consists of walls and door of pine planks of the region, rammed earth floor, and metal sheet roof. The bathroom is located on the outside, without storage tank, has concrete block walls, metal sheet roof and is connected to a septic tank. In Image 7, rural housing 2 is shown.

TImage 6. Rural housing 1

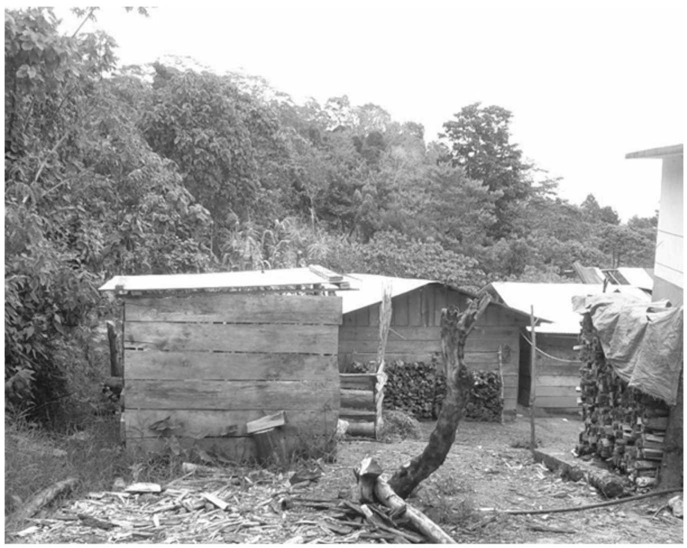
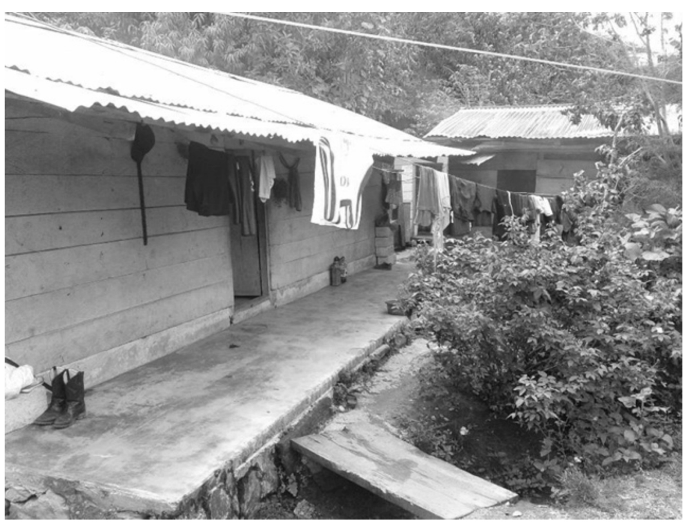


Image 7. Rural housing 2



The land where the rural housing 3 is, has 967 m² of total area, has two independent buildings and an isolated bathroom. One of the buildings is used as a room, with concrete block walls, doors and windows made of pine planks from the region, metal sheet roof and rammed earth floor. The other building is the kitchen, of walls and door of pine boards of the region, rammed earth floor and roof of metallic plate. The bathroom has no storage tank, it is connected to a septic tank, and it has concrete block walls, a blacksmith's door and a metallic sheet roof. Image 8 shows rural housing 3.

Image 8. Rural housing 3

Based on Image 5 and the quantification of the materials used in each rural house, for their construction, operation and maintenance, Tables 1, 2 and 3 were obtained. In these, the information is classified in the following sections: renewable resources, non-renewable resources, external material resources, tool and maintenance and operation.

The solar radiation that occurs during the construction, operation and maintenance processes was evaluated. The following were also considered: soil erosion (accepting that this is the loss of organic matter equivalent to the volume of excavation, approximately 3% of the volume of 1 m³), fuels, machinery, minor tool and labor (calories of human metabolism by hour per Joules per calories per hours of labor worked). The detailed calculation of the Raw Units column appears in the work of Vázquez Díaz (2016), from this same reference the data from the Transformity column was taken. In Tables

1, 2 and 3 the data of the RawUnits column is multiplied by the data of the Transformity column and the Solar eMergy is obtained in the last column.

For rural housing 1, it can be observed, in Table 1, that 45% of eMergy comes from wood energy, a renewable resource and that 39% comes from concrete, a non-renewable resource.

For rural housing 2 it can be seen, in Table 2, that 31% of eMergy is derived from wood energy, a renewable resource and that 58% comes from concrete, a non-renewable resource.

Finally, for rural housing 3 it is concluded, in Table 3, that 48% of the eMergy comes from the concrete's energy, a non-renewable resource, that 21% is derived from the concrete block and that 6% results from the wood, a renewable resource.

Table 1. Environmental assessment of rural housing 1

Note	**Concept**	**Raw Units** (unit/viv.)		**Transformity** (seJ/unity)	**Solar eMergy** (seJ/viv,)
Renewable resources					
1	Solar energy	3.09E+11	J	1.00E+00	3.09E+11
2	Wood	3.85E+10	J	6.79E+08	2.61E+19
Non- renewable resources					
3	Soil	1.28E+10	J	7.37E+04	9.42E+14
4	Steel	3.44E+05	g	3.16E+09	1.09E+15
5	Concrete	1.26E+07	g	1.81E+12	2.27E+19
6	Mortar	4.61E+05	g	3.31E+12	1.53E+18
Materials					
7	PVC	3.92E+04	g	9.86E+12	3.86E+17
8	Copper	2.08E+04	g	3.36E+09	7.00E+13
9	Galvanized sheet	3.56E+05	g	3.16E+09	1.13E+15
10	Block	2.17E+06	g	3.68E+12	7.99E+18
11	Diesel	2.22E+09	J	6.60E+04	1.46E+14
12	Minor tool	2.18E+02	g	6.70E+09	1.46E+12
Services					
13	Labor	3.87E+08	J	4.77E+06	1.85E+15
	Total eMergy for the construction of housing =				5.87E+19
Maintenance					
14	Wood	3.45E+09	J	6.79E+08	2.34E+18
15	Sheet	3.59E+04	g	3.16E+09	1.13E+14
16	PVC	2.46E+03	g	9.86E+12	2.43E+16

	Total eMergy for the housing's maintenance =				2.37E+18
Operation					
17	Solar energy	2.68+12	J	1.00E+00	2.68E+12
18	Electricity	1.84E+09	J	1.74E+05	3.19E+14
19	Firewood	5.88E+03	J	1.87E+04	1.10E+08
20	Drinking water	1.08E+09	J	3.76E+06	4.07E+15
21	Other services	7.39E+02	$	4.59E+13	3.39E+16
	Total eMergy for the operation of housing =				3.83E+16
	Total eMergía for construction, operation and maintenance				**6.12E+19**

Table 2. Environmental assessment of rural housing 2

Note	**Concept**	**Raw Units** (unit/viv.)		**Transformity** (seJ/unidad)	**Solar eMergy** (seJ/viv,)
Renewable resources					
1	Solar energy	5.10E+11	J	1.00E+00	5.10E+11
2	Wood	3.91E+10	J	6.79E+08	2.65E+19
Non- renewable resources					
3	Soil	1.28E+10	J	7.37E+04	9.42E+14
4	Steel	4.00E+05	g	3.16E+09	1.26E+15
5	Concrete	2.79E+07	g	1.81E+12	5.05E+19
6	Mortar	4.61E+05	g	3.31E+12	1.53E+18
Materials					
7	PVC	2.61E+04	g	9.86E+12	2.57E+17
8	Copper	2.16E+04	g	3.36E+09	7.27E+13
9	Galvanized sheet	3.27E+05	g	3.16E+09	1.03E+15
10	Block	2.17E+06	g	3.68E+12	7.99E+18
11	Diesel	2.41E+09	J	6.60E+04	1.59E+14
12	Minor tool	2.18E+02	g	6.70E+09	1.46E+12
Services					
13	Labor	3.13E+08	J	4.77E+06	1.49E+15
	Total eMergy for the construction of housing =				8.68E+19
Maintenance					
14	Wood	3.91E+09	J	6.79E+08	2.65E+18
15	Sheet	3.27E+04	g	3.16E+09	1.03E+14
16	PVC	2.61E+03	g	9.86E+12	2.57E+16
	Total eMergy for the housing's maintenance =				2.68E+18
Operation					
17	Solar energy	3.88E+12	J	1.00E+00	3.88E+12
18	Electricity	1.84E+09	J	1.74E+05	3.19E+14
19	Firewood	9.81E+03	J	1.87E+04	1.83E+08
20	Drinking water	1.62E+09	J	3.76E+06	6.10E+15

21	Other services	7.94E+02	$	4.59E+13	3.64E+16
	Total eMergy for the operation of housing =				4.29E+16
	Total eMergía for construction, operation and maintenance				**8.95E+19**

Table 3. Environmental assessment of rural housing 3

Note	**Concept**	**Raw Units** (unit/viv.)		**Transformity** (seJ/unity)	**Solar eMergy** (seJ/viv,)
Renewable resources					
1	Solar energy	7.76E+11	J	1.00E+00	7.76E+11
2	Wood	2.58E+10	J	6.79E+08	1.75E+19
Non- renewable resources					
3	Soil	1.33E+10	J	7.37E+04	9.80E+14
4	Steel	3.99E+05	g	3.16E+09	1.26E+15
5	Concrete	2.42E+07	g	1.81E+12	4.37E+19
6	Mortar	1.29E+06	g	3.31E+12	4.28E+18
Materials					
7	PVC	3.92E+04	g	9.86E+12	3.86E+17
8	Copper	2.08E+04	g	3.36E+09	7.00E+13
9	Galvanized sheet	3.99E+05	g	3.16E+09	1.26E+12
10	Block	6.01E+06	g	3.68E+12	2.21E+19
11	Diesel	2.41E+09	J	6.60E+04	1.59E+14
12	Minor tool	2.18E+02	g	6.70E+09	1.46E+12
Services					
13	Labor	4.63E+08	J	4.77E+06	2.21E+15
	Total eMergy for the construction of housing =				8.81E+19
Maintenance					
14	Wood				1.75E+18
15	Galvanized sheet				1.26E+14
16	PVC				3.86E+16
	Total eMergy for the housing's maintenance =				1.79E+18
Operation					
17	Solar energy				5.45E+12
18	Electricity				2.41E+14
19	Firewood				1.00E+08
20	Drinking water				3.05E+15
21	Other services				4.39E+16
	Total eMergy for the operation of housing =				4.64E+16
	Total eMergía for construction, operation and maintenance				**8.99E+19**

Once the eMergy for each dwelling was calculated, by construction, operation and maintenance, the emergetic indexes were obtained by construction, according to Table 1 and the flow chart of Image 5. For rural dwelling 1, the emergetic flows of Table 4 were obtained.

Table 4. Emergetic flows by construction of rural housing 1

Symbol	Emergetic flows	Quantity	Unit
R	Renewable resources	2.61E+19	seJ
N	Non-renewable resources	2.42E+19	seJ
M	Materials and tools	8.38E+18	seJ
S	Services and labor	1.85E+15	seJ
Y	eMergy used	5.87E+19	seJ/year

Based on the data in Table 4, the main emergetic indexes for the construction of rural housing 1 were calculated, which appear in Table 5.

Table 5. Main emergetic indexes that are used in the construction of rural housing 1

Emergy Investment Ratio: EIR	(M+S)/(R+N)	1.66E-01
Non-renewable/renewable	(N+M)/R	1.25E+00
Service/free	S/(N+R)	3.66E-05
Service/resources	S/(R+N+M)	3.14E-05
Environmental Loading Ratio: ELR	(N+M+S)/R	1.25E+00
Renewable fraction of the eMergy used	R/U	4.45E-01
Emergy Yield Ratio: EYR	1+(1/EIR)	7.01E+00
Renewable Emergy Captured	R+(M+S)	3.12E+00
Emergy Sustainability Index: ESI	EYR/ELR	5.61E+00
Emergetic production cost	U = R+N+M+S	5.87E+19

In a similar way, Tables 6, 7, 8 and 9 were obtained for rural dwellings 2 and 3.

Table 6. Emergetic flows by construction of rural housing 2

Symbol	Emergetic flows	Quantity	Unit
R	Renewable resources	2.65E+19	seJ
N	Non-renewable resources	5.20E+19	seJ
M	Materials and tools	8.25E+18	seJ
S	Services and labor	1.49E+15	seJ
Y	eMergy used	8.68E+19	seJ/year

Table 7. Main emergetic indexes that are used in the construction of rural housing 2

Emergy Investment Ratio: EIR	(M+S)/(R+N)	1.05E-01
Non-renewable/renewable	(N+M)/R	2.27E+00
Service/free	S/(N+R)	1.90E-05
Service/resources	S/(R+N+M)	1.72E-05
Environmental Loading Ratio: ELR	(N+M+S)/R	2.27E+00
Renewable fraction of the eMergy used	R/U	3.06E-01
Emergy Yield Ratio: EYR	1+(1/EIR)	1.05E+01
Renewable Emergy Captured	R+(M+S)	3.22E+00
Emergy Sustainability Index: ESI	EYR/ELR	4.63E+00
Emergetic production cost	U = R+N+M+S	8.68E+19

Table 8. Emergetic flows for the construction of rural housing 3

Symbol	Emergetic flows	Quantity	Unit
R	Renewable resources	1.75E+19	seJ
N	Non-renewable resources	4.80E+19	seJ
M	Materials and tools	2.25E+19	seJ
S	Services and labor	2.21E+15	seJ
Y	eMergy used	8.81E+19	seJ/year

Table 9. Main emergetic indexes used in the construction of rural housing 3

Emergy Investment Ratio: EIR	(M+S)/(R+N)	3.44E-01
Non-renewable/renewable	(N+M)/R	4.03E+00
Service/free	S/(N+R)	3.37E-05
Service/resources	S/(R+N+M)	2.51E-05
Environmental Loading Ratio: ELR	(N+M+S)/R	4.03E+00
Renewable fraction of the eMergy used	R/U	1.99E-01
Emergy Yield Ratio: EYR	1+(1/EIR)	3.91E+00
Renewable Emergy Captured	R+(M+S)	7.78E-01
Emergy Sustainability Index: ESI	EYR/ELR	9.71E-01
Emergetic production cost	U = R+N+M+S	8.81E+19

Based on the data in Table 1, and the flow chart in Image 5, the emergetic flows for maintenance and operation of rural housing 1 were calculated, the results are shown in Table 10.

Table 10. Emergetic flows for maintenance and operation of rural housing 1

Symbol	Emergetic flows	Quantity	Unit
R	Renewable resources	2.34E+18	seJ
N	Non-renewable resources	4.39E+15	seJ
M	Materials and tools	2.44E+16	seJ
S	Services and labor	3.39E+16	seJ
Y	eMergy used	2.40E+18	seJ/year

Based on the data in Table 10, the main emergetic rates for maintenance and operation of rural housing 1 were calculated, which appear in Table 11.

Table 11. Main emergetic indexes that are used in the maintenance and operation of rural housing 1

Emergy Investment Ratio: EIR	(M+S)/(R+N)	2.48E-02
Non-renewable/renewable	(N+M)/R	1.23E-02
Service/free	S/(N+R)	1.45E-02
Service/resources	S/(R+N+M)	1.43E-02
Environmental Loading Ratio: ELR	(N+M+S)/R	2.68E-02
Renewable fraction of the eMergy used	R/U	9.74E-01
Emergy Yield Ratio: EYR	1+(1/EIR)	4.12E+01
Renewable Emergy Captured	R+(M+S)	4.02E+01
Emergy Sustainability Index: ESI	EYR/ELR	1.54E+03
Emergetic production cost	U = R+N+M+S	2.40E+18

In a similar way, Tables 12, 13, 14 and 15 were obtained for rural dwellings 2 and 3.

Table 12. Emergetic flows for maintenance and operation of rural housing 2

Symbol	Emergetic flows	Quantity	Unit
R	Renewable resources	2.65E+18	seJ
N	Non-renewable resources	6.42E+15	seJ
M	Materials and tools	2.58E+16	seJ
S	Services and labor	3.64E+16	seJ
Y	eMergy used	2.72E+18	seJ/year

Table 13. Main emergetic indexes that are used in the maintenance and operation of rural housing 2

Emergy Investment Ratio: EIR	(M+S)/(R+N)	2.34E-02
Non-renewable/renewable	(N+M)/R	1.22E-02
Service/free	S/(N+R)	1.37E-02

Service/resources	S/(R+N+M)	1.36E-02
Environmental Loading Ratio: ELR	(N+M+S)/R	2.59E-02
Renewable fraction of the eMergy used	R/U	9.75E-01
Emergy Yield Ratio: EYR	1+(1/EIR)	4.37E+01
Renewable Emergy Captured	R+(M+S)	4.26E+01
Emergy Sustainability Index: ESI	EYR/ELR	1.69E+03
Emergetic production cost	U = R+N+M+S	2.72E+18

Table 14. Emergetic flows for maintenance and operation of rural housing 3

Symbol	Emergetic flows	Quantity	Unit
R	Renewable resources	1.75E+18	seJ
N	Non-renewable resources	3.29E+15	seJ
M	Materials and tools	3.87E+16	seJ
S	Services and labor	4.31E+16	seJ
Y	eMergy used	1.84E+18	seJ/year

Table 15. Main emergetic indexes that are used in the maintenance and operation of rural housing 3

Emergy Investment Ratio: EIR	(M+S)/(R+N)	4.67E-02
Non-renewable/renewable	(N+M)/R	2.40E-02
Service/free	S/(N+R)	2.46E-02
Service/resources	S/(R+N+M)	2.41E-02
Environmental Loading Ratio: ELR	(N+M+S)/R	4.86E-02
Renewable fraction of the eMergy used	R/U	9.54E-01
Emergy Yield Ratio: EYR	1+(1/EIR)	2.24E+01
Renewable Emergy Captured	R+(M+S)	2.14E+01
Emergy Sustainability Index: ESI	EYR/ELR	4.61E+02
Emergetic production cost	U = R+N+M+S	1.84E+18

The above results are summarized, for comparison purposes, in Tables 16 and 17, for the 3 rural dwellings.

Table 16. Emergetic indexes for construction of the 3 rural dwellings

Indexes		Rural housing 1	Rural housing 2	Rural housing 3
Emergetic production cost	U=R+N+M+S	5.87E+19	8.68E+19	8.81E+19
Renewable fraction of the eMergy used	R/U	0.445	0.306	0.199
Emergy Investment Ratio: EIR	(M+S)/(R+N)	0.166	0.105	0.344

Emergy Yield Ratio: EYR	1+(1/EIR)	7.010	10.522	3.911
Environmental Loading Ratio: ELR	(N+M+S)/R	1.249	2.272	4.029
Renewable eMergy Captured	R/(M+S)	3.117	3.216	0.778
Emergy Sustainability Index: ESI	EYR/ELR	5.612	4.631	0.971

Emergetic indexes allow us to establish the environmental status of the studied system, based on these indicators, the system can be analyzed and diagnosed, and with this, decisions can be made in environmental management and public policy direction in planning. For the present evaluation, the eMergy Investment Ratio (EIR), the EMergy Yield Ratio (EYR), the Environmental Loading Ratio (ELR) and the EMergy Sustainability Index (ESI) were considered.

The EIR index (or investment ratio), indicates the investment made by the company involved in the production chain to produce a good, in relation to the contribution of nature. It results from dividing the solar eMergy taken from outside the system, between the solar eMergy supplied by renewable and non-renewable sources within the system. This quotient can be interpreted as an external (inverted) eMergy rate, with respect to resident eMergy. It is a dimensionless number, the higher it is, the greater the amount of eMergy acquired, per unit of resident eMergy (high values of EIR indicate a high contribution of external eMergy). Small values of EIR show a relative small load on the base ecosystems, this indicates that they are using their own environmental resources, to a greater extent than the average, so there could be local availability to stimulate investment and additional economic use.

When observing the results of Table 16, it is noted that, in terms of construction, rural housing 2 is the most competitive, since for each unit of natural resources used (with no financial cost), it needs to invest a smaller volume of economy resources.

The Emergy Yield Ratio (EYR), results from dividing the total eMergy used by the system among the eMergy of the economy inputs. It is a measure of the primary energy gain available for use by society, that is, measures the potential contribution of a process to the whole system due to the exploitation of local resources. From table 16 it can be inferred that, as far as construction is concerned, rural housing 2 is more efficient, since it uses natural resources and resources from the economy. In other words, it is capable of providing primary energy for society.

The Environmental Loading Ratio (ELR) is a measure of the environmental impact or burden that a particular development activity can have on the environment (Guillén Trujillo, 1998). This index results from the sum of the acquired eMergy (M and S) and the nonrenewable resident eMergy (N), among the renewable resident eMergy (R). It can be used as an indicator of the appropriate level of the alternatives development to carry out a project. The majority of the productive processes of humanity include the interaction between non-renewable resources with renewable resources of the environment. Low Environmental Loading Ratio (ELR) indicates small loads at the base of the ecosystem support; high ELR indices reflect a greater potential impact. The results of Table 16 indicate that, regarding to construction, rural housing 1 is the one that causes the least impact on the environment.

The Emergy Sustainability Index (ESI) results from dividing the eMergy Emergy Yield Ratio (EYR) between the Environmental Loading Ratio (ELR). Quantify and numerically classify the environmental performance of a country's policies, and it is an effective extent to measure the long-term sustainability perspectives of the environment and the capacity to face the challenges of the future. ESI values below 1.00 are characteristic of systems that consume resources and are associated with highly developed and consumption-oriented economies. According to Table 16, rural housing 1, in terms of construction, is the one with the least environmental impact, since it contributes to the release of resources available for use by the economic sector, without affecting the balance of the environment.

Table 17. Emergetic indexes for maintenance and operation of the 3 rural dwellings

Indexes		Rural housing 1	Rural housing 2	Rural housing 3
Emergetic production cost	U=R+N+M+S	2.40E+18	2.72E+18	1.84E+18
Renewable fraction of the eMergy used	R/U	0.970	0.970	0.950
Emergy Investment Ratio: EIR	(M+S)/ (R+N)	0.020	0.020	0.050
Emergy Yield Ratio: EYR	1+(1/EIR)	41.240	43.700	22.420
Environmental Loading Ratio: ELR	(N+M+S)/R	0.030	0.030	0.050
Renewable eMergy Captured	R/(M+S)	40. 170	42.600	21.380
Emergy Sustainability Index: ESI	EYR/ELR	1540.610	1687.520	461.010

When observing Table 17 results, it is noted that for the EIR index, in terms of maintenance and operation, rural dwellings 1 and 2 are the most competitive, since for each unit of natural resources used (without financial cost), they need to invest a smaller volume of resources in the economy.

From this same table it is inferred that for the EYR index, in regards to maintenance and operation, rural housing 2 is more efficient, since it uses natural resources and resources from the economy in its processes. In other words, it is capable of providing primary energy for society.

The Environmental Loading Ratio, in Table 17, indicates that regarding maintenance and operation, rural housing 3 has a moderate impact and rural housing 1 and 2 have the least impact on the environment.

In this same table, the sustainability index of rural housing 2, in terms of maintenance and operation, shows that this building has less environmental impact, because it contributes to the release of resources available for use by the economic sector, without affecting the balance of the environment.

CONCLUSIONS

Housing construction involves processes, which require materials and energy inputs in different ways, and has a great impact on the environment through the use of non-renewable resources and the overexploitation of energy. In this work, an eMergy analysis was carried out on three rural dwellings, considering three separate phases: construction, maintenance and operation; this makes it possible to have a measure of the environmental impact of these homes in their environment.

This method is useful for identifying the inputs that contribute most to non-renewable energy imports. The importation of resources gives an idea of a lack of economic sustainability, while the fact that it is not renewable suggests a future shortage due to a dependence on the actual availability of resources on land.

The results show that, in general, rural dwellings are sustainable, that is, they take advantage of natural conditions to reduce energy needs as much as possible. As a result, the wear and tear of nature is less and the houses are able to maintain themselves economically, socially and ecologically.

Rural housing 2 showed advantages in the construction phase, in terms of Emergy Investment Ratio (EIR), and Emergy Yield Ratio (EYR). This indicates that such housing has a small relative burden on the base ecosystems and that it offers a net benefit to the global economy.

For this same phase, rural housing 1 presented good results in terms of the Environmental Loading Ratio (ELR) and the Emergy Sustainability Index (ESI), from which it is inferred that this house causes little environmental stress in the system and that they have a high level of sustainability in environmental terms.

The evaluation for the maintenance and construction stages indicates that rural dwellings 1 and 2 have a better Emergy Investment Ratio (EIR) than rural dwelling 3. The latter stresses the environment less (due to its Environmental Loading Ratio, ELR), than the other two homes. Finally, rural housing 2 also showed a good Sustainability Index (ESI), higher than that of rural dwellings 1 and 3.

In general, the results of rural housing 2 indicate that it is sufficient to cover the needs of its inhabitants and that its maintenance is not expensive.

Additionally, the results obtained here provide a basis for future evaluations in the construction industry. Different typologies, technologies and materials can be compared and contrasted, considering different manufacturing processes, as well as maintenance and operation (durability of a material, thermal efficiency and energy consumption during its useful life). These comparisons can be made objectively using the eMergy indices as shown here.

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