Emergy Synthesis and Sustainability: Analysis of Emergy Flows in the Territorial Dynamics in the Municipality of Pitalito - Huila

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Abstract

This work shows the application of emergy synthesis in the municipality of Pitalito a small territory located in the Department of Huila in southwestern Colombia, the purpose of this application is to establish a basis of analysis for the identification of environmental, social and productive relationships in the systems under study, as well as the dynamics of generation, use and exploitation of energy in their processes, analyzing the energy intensity, environmental pressure, the structure of existing resources and the efficiency of their use. The analysis allowed to quantify the primary renewable flows and reserves, the dynamics and effects of productive and extractive activities in the territory, as well as the different interrelationships between flows, energy efficiency and sustainability in the framework of the integration of energy, territory and development -ETD- with a systemic vision, allowing the identification of critical points for the formulation of measures, decision making and policy approaches for territorial sustainable development.

Keywords: *emergy synthesis, sustainability, territory*

1. Introduction

There are three integrating concepts that has been attributed to Sustainable Development (SD): environment, economy and society (Cohen, Sweeney, King, Shepherd and Brown, 2012). The integration of these aspects generates impacts from the growth and exploitation of natural resources (use of energy and non-renewable sources) to the generation of services, (Vito Comar, 1998), (Brown, Green, González, and Venegas, 1992). There are studies of different approaches to assessing sustainability or "metabolism" in regions in both cities and urban areas (Kennedy at al, 2007), with examples in Taipei (Huang, 1998), Macao (Lei et al, 2008), Rome (Ascione et al, 2011) or Beijing (Zhang et al, 2011). In general, dynamic analyses of material flow accounting or metabolism systems include ecological footprint studies, life cycle analysis, and population energy consumption; The latter is a key factor in the dynamics of these interactions, being a key force in the development processes.

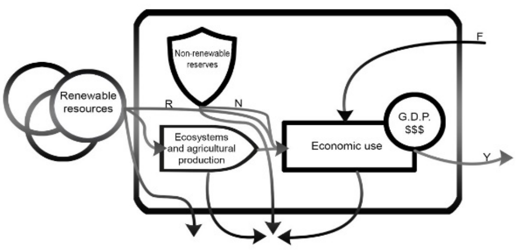
Energy It is also understood as the main driver of anthropogenic changes linked to climate change (Howard et al., 2013). The study of the relationship between Energy, Territory and Development (ETD) requires finding a balance between the maximization of the expected results in the systems analyzed and the minimization of the negative impacts derived from the existing processes, which makes it necessary to model the particular situation and state of the territory and its future scenarios (Bandini, et al., 2011), promoting the search for environmentally friendly, socially acceptable and cost-effective solutions through the integration of tools (Mirakyan and De Guio, 2013) and the application of quantitative methods for the modeling of ETD systems (Vega et al., 2013). Emergy is one of the quantitative methods that includes the basic flows of energy, materials and resources in a system (environmental, socio-economic, currency and labor) through a common unit of measure, the solar emjoule (seJ) and it is described as "the total amount of available energy of a type (usually solar) that is required directly and indirectly to produce a given product or to support a given flow" (Odum, 1996). Emerging calculations make it an appropriate methodology for assessing and comparing the sustainability of rural areas and cities, as they integrate the different types of flows that interact in urban ecosystems (Ascione et al., 2011).

With the aim of describing the size and interrelations of a territory, as well as its productive dynamics and the existing strategies around the processes of generation, use and exploitation of energy, this work presents the emergetic synthesis as a support to the analysis of the flows of resources, energy, materials and information (Campbell & Ohrt, 2009) through a case study applied in the municipality of Pitalito in the Department of Huila in the southwest of Colombia.

2. Methods

This study follows the guidelines for the emergy analysis of territories proposed in (Odum, 1996) (Agostinho, Sevegnani, Almeida, & Giannetti, 2016) in which three stages of implementation are defined: preparation of the diagram, calculation, and analysis of flows and evaluation of indicators, also allowing the review of the impact of human activities and the changes caused by them in a area. This evaluation was carried out in the municipality of Pitalito, in the Department of Huila, in southwestern Colombia, seeking to obtain an integrating view of the dynamics and energy flows in this territory.

Given the nature of the system analyzed, the general diagram model proposed by Brown was chosen as the basis for the analysis of territorial systems with urban-rural interrelationships (Brown et al., 1992) as shown in Figure 1.



Emergy Synthesis diagram for territorial system

Letter	Assignation
R	Flows from Renewable Sources
N	Non-Renewable Flows
F	Inputs to the system from the environment
Y	Energy contribution, the sum of R, N and F flows

Fig1. Emergy synthesis diagram for territorial systems.

For the calculation of flows and related indicators in this study, priority was given to existing primary sources of information in Geographic Information Systems (GIS) using official mapping and scientific studies processed through the ARCGIS application; existing data for the years 2014 and 2015 were used as a basis, the values for transformity were taken mainly from Odum (1996) and Campbell & Ohrt (2000).

3. Results

3.1 Description of the territory and energy flows

Located in southwestern Colombia at an average altitude of 1,318 meters above sea level, Pitalito has an area of 626.07 km2 and 125,839 inhabitants (DNP, 2016a), its economy is agricultural and crops occupy a space of approximately 48.1% of the territory, with 21 products that make up the productive vocation, being coffee, with an area of 20,154 hectares planted the main crop of the municipality (Ministry of Agriculture, 2016), although coffee production, despite its volume, represents only 8% of the municipal added value in economic terms (DNP, 2016a). Industrial processes are complemented by livestock and pig breeding and exploitation, mining, and commercial and service activities (Pitalito City Hall, 2016). Table 1, shows the calculation of the different energy flows that make up the dynamics of the territory; The total use of energy is 2.54E+21 sej, where the main contribution is concentrated in the use of indigenous resources with 59%, followed by imported flows with 32% and finally a contribution of 9% of geobiophysical flows that make up the territory, demonstrating the high degree of dependence of this to its indigenous resources, mainly land.

Table 1. Summary of energy flows in Pitalito based on 2014-2015 data

ID	Ítem	Value	Unit	Transformity (sej/unit) *	Emergy
			RENEWABLE FLOWS		
1	Solar (received)	3,59E+18	J	1	3,59E+18
1	Solar (Absorved)	2,98E+18	J	1,21	3,60E+18
2	Rain, Chemical	5,10E+15	J	18100	9,24E+19
2	Rain, Geopotential	1,34E+16	J	10100	1,35E+20
3	Wind, kinetic	4,93E+16	J	1467	7,24E+19
	R (Renewable flow)			**2,27E+20**	
			Indigenous reneable energy		
4	Agriculture production	5,79E+14	J	336000	1,94E+20
5	Cattle	1,06E+14	J	3360000	3,58E+20
6	Fisheries	3,34E+11	J	3360000	1,12E+18
7	Forrest extraction	1,96E+16	J	22100	4,34E+20
			Non renewable sources from within the system		
8	Sand extraction	5,72E+10	g	1310000000	7,49E+19
	Extracción de arcill	4,32E+09	g	1960000000	8,47E+18
9	Soil loss (SL)				
	SL populated centers	3,44E+15	J	106000	3,64E+20
	SL rural use	5,04E+14	J	106000	5,35E+19
	SL Forrests	1,91E+12	J	106000	2,03E+17
	N0.			**6,71E+20**	
	N1.			**8,34E+19**	
	N			**1,49E+21**	
			IMPORTED RESOURCES		
10	Imported resources				8,26E+20
	F (Imported flows)			**8,26E+20**	
	Total emergy use = No + N1 + R + F			**2,54E+21**	

INPUT VALUES TO THE CALCULATION MODEL AND REFERENCES						
Área	km2 6.260,784	m2 626.078.400	ha 62607,84			
RENEWABLE SOURCES						
Note	**Source / Flow**	**Equation and notes**				**Reference**
	Received (J) = (Energy reaching the system)	**(average radiation)(area)(365 days/year)(Conversion factor to J)**				Odum, 1996
1.Solar Energy	Absorbed (J) = (Energy used in the transformations in the systems under study)	**(Received)(1-albedo)**				
	Pitalito is in the 3.5 to 4.5 kWh/m2dia range, obtained by calculation of isolines in the IDEAM solar radiation Atlas.					Ideam, 2016
	Average radiation	4,36 kWh/m2dia,				NASA, EOS, 2016
		Albedo	0,17			Nasa, EOS, 2016
	Solar energy received	3,59E+18				
	Solar energy absorbed	2,98E+18				
	Chemical =	(area)(Precipitation)(water density)(Gibbs free energy)(Gibbs free energy)				Odum, 1996
	Geopotential =	(area)(mean elevation)(rainfall)(density)(severity)				
		Lluvia	4,52	16498	mm día -	NASA EOS, 2016
		Elevación	1318			Alcaldía Pitalito, 2015
2. Rain	According to the development plan of the municipality of Pitalito and the document "Pitalito Change Route 2030, the average rainfall is in the 1070-2700 mm/year range. The value presented by Nasa was taken					Alcaldía Pitalito, 2016
	Rain - Chemical	**5,10255E+20**				
	Rain - Geopotential	**1,3355E+20**				
	Energy wind =	(density)(Drag coefficient)(wind speed)^3(area)(sec/year)				Odum, 1996
		Carry-over coefficient	0,003	Sobre montaña		Campbell & Ohrt (2009)
		Wind speed varies between 0-3 m/s				Alcaldía Pitalito, 2016
3. Wind		Density	1,3	kg/m3		Campbell & Ohrt (2009)
		Wind speed	8615125	m/s		NASA EOS, 2016
		Coeficiente arrastre	3,00E-03			Campbell & Ohrt (2009)
	Energy from the wind	4,93E+16				
AUTOCHTHONOUS RENEWABLE ENERGY						
4 Agricultural production	Agricultural production =	(Total production * Energy content)				Odum, 1996
	Agricultural production	5,79E+14	J (Energy content of total agricultural production)			Gobernación del Huila, 2016
5.Cattle raising	Livestock = (Production T)(conversion factor T to g)(energy factor - Lime/g)(4186 J/lime)					Gobernación del Huila, 2016
	Livestock production	1,06E+14				FAO, 2016
6. Fishing(crops)	Energy Fishing =	(T production)(conversion factor T to g)(energy factor - Lime/g)(4186 J/lime)				Gobernación del Huila, 2016 FAO, 2016
	Fishing	3,34E+11				
	Forest extraction =	(Volume extracted in M3)(conversion factor from m3 to cm3)(average forest energy content 10176 j/cm3)				
	extraction (ha) =		193	ha/año		Plan desarrollo 2016. Pitalito
7. Forest extraction	extraction (m3) =		1930000	* Surface to volume value approximated		
	Forest Energy Content (J/cm3) =		10176			Campbell & Ohrt (2009)
	Forest extraction	1,96E+21				
NON-RENEWABLE SOURCES IN THE SYSTEM						
	Energy content =	mass of material extracted * energy available				Campbell & Ohrt (2009)
	Sand		21580	m3	2650 kg/m3	DNP, 2016b
	Ceramic clays		3312	T		
8. Mining extraction	Ferruginous clays		1010	T		
	Energy Disp. Sand		1,31E+09			Campbell & Ohrt (2009)
	Energy Disp. Clays		1,96E+09			
	Energy content Sand	7,49E+19				
	Energy content Clays	8,47E+18				
	Loss of soil =	(area)(erosion)(organic fraction)(energy)				Campbell & Ohrt (2009)
	Agricultural Use		20660	ha	2,07E+08	DNP, 2016ª
	Town centres and other uses		2112	ha	2,11E+07	
	Forests		17610	ha	1,76E+08	
	Erosion in Pitalito		According to the Agustín Codazzi Geographic Institute, erosion in the municipality is among non-			IGAC, 2016
	Erosion	27	Se asume un valor moderado de acuerdo con la proporción de áreas analizadas por IGAC			
	Organic matter	0,04	Between 1000 and 2000 meters above sea level in the Department of Huila there are			IGAC, 1994
	Erosion Population centre	The calculation model proposed by Agostinho (2016) is used				Agostinho y otros, 2016
9. Loss of soil	emerges loss of land center populated (sej/year) =		urban area (m2/year) * fertile depth (0.15m) * soil density (1200 kg/m3) * organic matter			
	Loss of land Village centre	3,44E+15				
	Soil loss Forests	The IGAC erosion map places erosion in a reserve zone between non-existent and non-appreciable. A value of 0.12 T/ha derived from the literature is assumed				IGAC, 2016
		Erosion	0,12			
		Energy content	22604	J/g		Campbell & Ohrt (2009)
	Loss of forest soil - Forests	1,91067E+17	J			
	Loss of land for agriculture and livestock	5,04359E+19				
IMPORTED RESOURCES						
	F	ID=0,2516*(DD)^1,0451	Intensity of imports			Agostinho y otros, 2016
		DD = Density of development. USD/km2. GDP of the territory by area				
		F=ID*área*EMR	EMR = Emergy to money ratio (Emerging rate-Money)			CEP, 2016
			For Colombia EMR = 3.9E+12			
	1,26E+12	GDP Pitalito				
10. Imported resources	4,58E+08	GDP In USD		2015	2746 $/USD	Banco de la república
	7,31E+05	GDP(USD)/AREA				
	3,90E+12	EMR Colombia				CEP, 2016
	2,75E+21	U			2,19E+09	
	ID	338147,09			4,6E-07	
	F	8,26E+20				

Renewable flows (R)

The purpose of establishing a renewable flow base in the study of an ETD system is to assess the extent to which renewable land sources have been concentrated in the area under investigation and their contribution to development (Campbell & Ohrt, 2009). The primary renewable flow (R) calculated corresponds to rainfall that contributes to processes such as landscape formation, water distribution, biomass growth, among others (Odum, 1996; Agostinho et al., 2016). This flow represents a total contribution of 2.27E+20 sej, although it is important to highlight the contribution of solar radiation, with a total of 3.60E+18 sej, absorbed and high wind potential, for the development of energy projects.

Indigenous renewable flows

The most significant emergy flow of productive sectors that use primary renewable energy sources for the production of some secondary energy corresponds to forest exploitation with 44%. The forest cover reaches an approximate area of 17,610 ha. (Municipality of Pitalito, 2016; DNP, 2016a), the leading causes of loss of coverage being the processes of "leñateo" for cooking food, the opening of areas for new crops, fires of vegetation cover and threats such as climate variability and the process of road development and population growth in the municipality. In addition to the potential impact on the use of energy flows from the exploitation of forest resources, the analysis shows an essential share of agricultural production with a contribution of 1.94E+20 sej (20% of flows), as well as livestock production, which represents 36%. Based on the production, yield and cultivated area data obtained from Agronet (Ministry of Agriculture, 2016), it is possible to establish that between 2007 and 2014 the total area grew by 6.977 ha that represents, in the 7 years analyzed, an increase of 11.1% in the use of the territories in the expansion of agricultural activities; in this dynamic the cultivation of coffee trees is the main contributor in the use of the land, as well as the main consumer of energy, flows from autochthonous sources with a contribution in the increase of land use of 8.838 ha, while traditional maize and cassava decreased in size (1,130 and 530 ha respectively). Figure 3 shows the energy contribution of existing crops in the municipality.

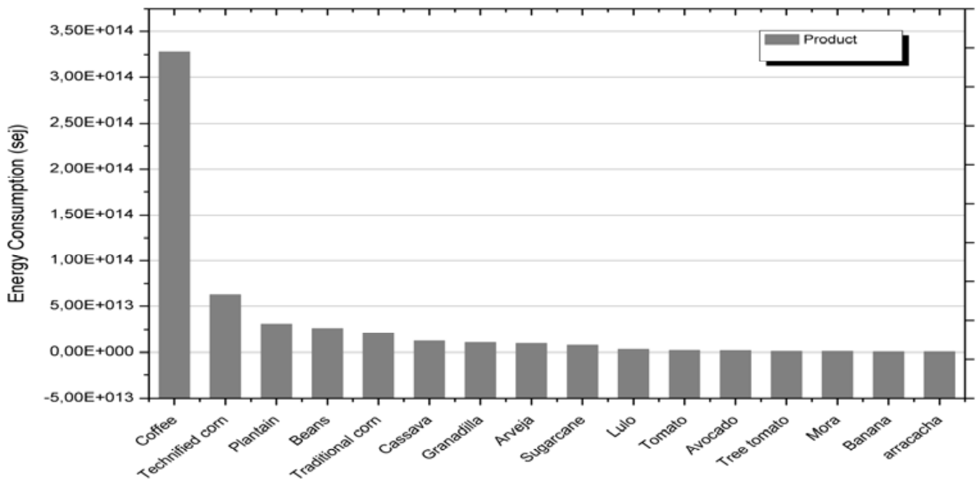


Fig. 2. Emergy consumption for agricultural products.

The consumption of livestock production according to the regional information system of Huila represents 36%, the primary product being livestock with an output of 4,388 tons (Government of Huila, 2016). Milk production reached 7,327,740 liters of milk per year with an energy contribution of 5.26308E+13 sej. In pigs, slaughter data were found for 3,600 animals, with an output of 302 tons of meat (Gobernación de Huila, 2016).

Non-renewable flows

Emerging flows of non-renewable resources include, but are not limited to, soil loss through erosion and the flow of products derived from extraction such as coal, natural gas, oil, mining and metals; in the analysis of dual systems (urban-rural), experience has shown that the most significant influence comes typically from land loss processes due to urbanization, and rural use (Agostinho et al., 2016). Soil loss is analyzed using the Agostinho et al. model (2016), which considers soil waterproofing and the total loss of ecosystem functions such as food production and life support for different species due to urbanization, as well as injuries linked to agricultural processes and the existence of buffer and reserve zones. According to the National Planning Department, in the general royalty system there are reports of clay extraction (ceramics, ferruginous and miscellaneous), sand and gravel from rivers and streams (DNP, 2016b), essential materials not only in the development of extractive activities, but also in the production of artisanal bricks and tiles (Mayor of Pitalito, 2016).

The analysis of this flow is vital given that the phenomenon of erosion decreases the value of natural capital assets in the territory (Campbell & Ohrt, 2009). For the department of Huila, there is a general study of soils carried out by the IGAC in 1994 (Instituto Geográfico Agustin Codazzi, 1994) and there are also data available in the geographic information system for territorial planning of the same institution (Instituto Geográfico Agustín Codazzi, 2016). In both cases, a presence of "no erosion" to "moderate" degrees can be seen in the south of the department. (Colombian Environmental Information System, 2016).

The calculation of energy consumption due to soil loss shows that the main non-renewable flow corresponds to the damage associated with urbanization, which represents more than 85%. Long and Ulgiati (2016) analyzing the problem show that the urbanization process could accelerate energy demand and greenhouse gas emissions, indicating that the urbanization process can have particular effects on territorial energy efficiency. The loss of land in agricultural operations has a cost of 5.35E+19 sej whose long-term effect could demand a higher flow of imported resources to compensate for losses in this area. Given the economic importance of the agricultural processes in the municipality, which show the high impact of coffee on the productive, economic and social dynamics, the following shows the evolution of flows in this area according to the growth in the area dedicated to crops and coffee production.

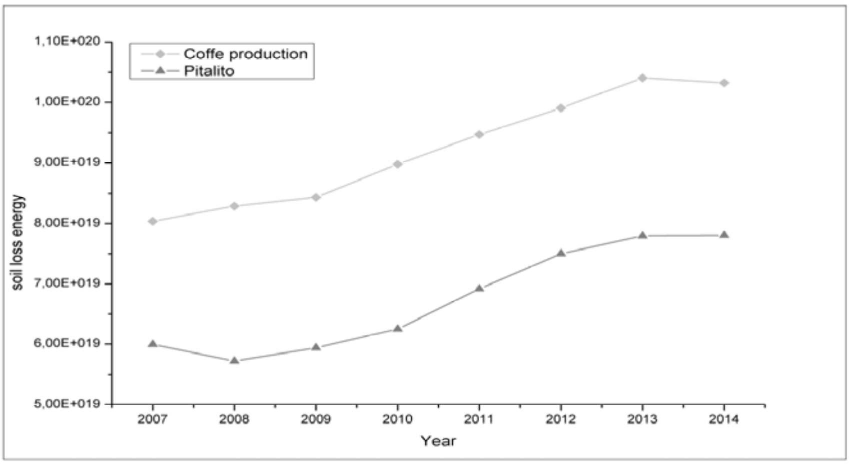


Fig. 3. Evolution of emergy consumption due to soil loss in coffee and agriculture.

Imported flows (F)

The consumption of imported resources corresponds to the subsidized fraction, or the extra contribution required by the systems to increase productivity, which represents an essential contribution to the environmental costs, impacts, and competitiveness of the operations (Jordan, 2013). However, given the difficulty of finding specific data on these elements in small territories or municipalities, it is necessary to use alternative mechanisms of analysis, in this case, the calculation equations developed by Agostinho and others are used (2016).

According to figures published by DANE (DANE, 2015), in 2015 the added value of the municipality of Pitalito was USD 457 million. From these data, the consumption of imported resources was determined:

The flow of imported resources (F): 8,26E+20 sej

The flow is based on the fact that agricultural production costs, compared with municipal GDP, represent 12% of the total. It can be seen that transport, with 9% and coffee cultivation with 8% are representative of this result, demonstrating the potential impact of efficiency in the processes related to the latter on the dynamics and sustainability of the territory (Government of Huila, 2016). Aggregate energy balance and indicators. The aggregate energy flows are shown in the following figure, where the total values of the aggregate flow entering the analyzed territorial system can be appreciated: Renewable resources (R), Non-renewable resources (N0, N1) and imported resources (F).

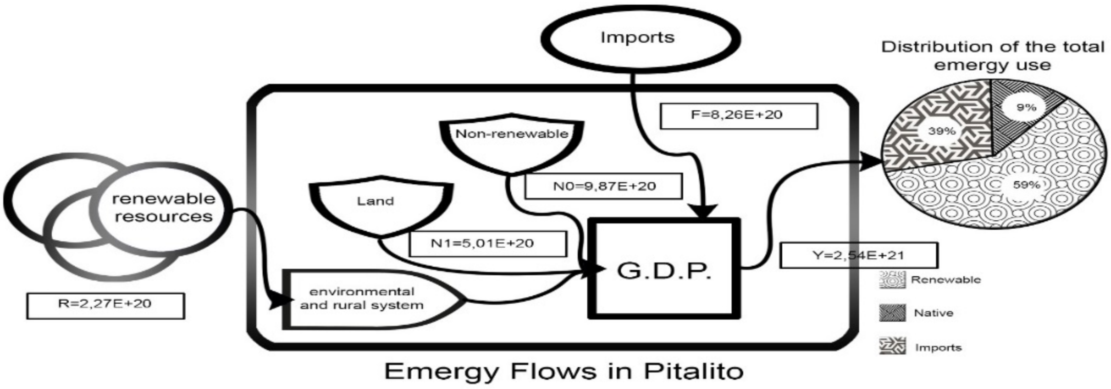


Fig. 4. Emergy flows in Pitalito.

The most excellent consumption is made up of the dispersed flows (N0) that are related to the productive agricultural activity in the territories. Concentrated streams (N1) show the high energy costs associated with soil loss and erosion processes associated with farming. Likewise, the Emergy Money Ratio (EMR) was calculated, which represents the energy consumption per monetary unit, or the energy support of the system in the generation of value and its contribution to the economy that gives an amount of 5.55E+12 sej/USD. Table 2 shows the summary of the calculated indicators.

Table 2. Emergy indicators

Indicator	Formula	PITALITO
Renewable flows	R	2,27E+20
Non-renewable flows	N	1,49E+21
Imported flows	F	8,26E+20
Total emergy consumption (YU)	**N0+N1+R+F**	**2,54E+21**
Fraction derived from home sources	(NO+N1+R) /U	0,68
Fraction, locally renewable	R/U	0,09
Fraction purchased	(F)/U	0,32
The fraction that is free	(R+N0) /U	0,48
Use per unit área	U/ (área ha)	4,06E+16
Use per person	U/población	2,02E+16
Emergy Money Ratio	U/PIB municipal	5,55E+12
Environmental loading ratio (ELR)	(Imp + N0 + N1) / R	10,18
Environmental yield ratio (EYR)	U / (N0 + N1 + F)	1,1
Environmental sustainability	EYR / ELR	0,11

index (ESI)

For the analysis of efficiency, the main performance indicators reviewed in the literature related to emergética synthesis were considered. The ELR index assesses the balance between non-renewable and renewable resources consumed in the territory, with the result that the higher the values, the lower the sustainability of the system under study. This value becomes greater as the more economic activity is concentrated in the territories, with values above 1000 (Brown & Ulgiati, 2001). The result obtained (10.18), in this context can be understood as a low load rate that shows the critical value that natural resources represented in the territorial systems analyzed (Vega et al., 2013). In which, the specific weight of coffee in this dynamic has already been demonstrated.

The energy yield rate (EYR) makes it possible to measure at what level the existing processes in the territory contribute to its energy development, linking total energy consumption against the import of resources from outside the system. Values higher than 1 indicate that they can be sustained by local resources to generate net benefits to society (Ren, Manzardo and others, 2013). The Emerging Sustainability Index (ESI) is an indicator that aggregates the performance and environmental burden of the system under analysis, allowing the possibilities of sustainable development to be assessed (Guan et al., 2016). Even though in the context studied, the values obtained in the calculation of the ELR and EYR indicators show a positive outlook, there is also a low value of energy sustainability (0.11). An emergética sustainability index of less than 1 indicates a temporary problem for the analyzed territories since it explains that the products and processes are not sustainable in the long term, (Ren, Manzardo and others, 2013).

Conclusions

The emergetic synthesis model has made it possible to analyze national systems in their relationship with energy consumption and development processes, providing a holistic view of the flows of matter, energy as well as information that make up the dynamics, structure and fundamental operations of the territory. Thus, the study of the case of Pitalito has allowed us to identify how the water and rain cycle is a critical component in the use of renewable energy resources, coffee as a product of high impact on energy consumption in the territory and a high dependence on economic resources turned by the central government.

The structure of emergetic consumption in Pitalito is composed of 59% of the use of indigenous resources, with a substantial contribution of soil loss and the non-renewable exploitation of existing resources in the territory; likewise, the use of imported emergetic flows, which corresponds to 32% of the total consumption of emergetic streams and 9% of geophysical resources. These results show the high dependence of the territory on the extraction of energy from its indigenous sources, indicating a dynamic of weak sustainability in the long term.

This last conclusion is evident from the values obtained in the ELR calculation, which showed an essential amount of natural resources, an emergy rate of return that places the dynamics of the territory at the limit of the dependence on external sources and an ESI index that generates doubts about the long-term sustainability of the land, demonstrating in some way how, despite being a small, rural area and in theory of simple management, the particular decisions on the productive structure.

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