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Emergy-Based Assessment of Territorial Sustainability in Palmira, Colombia

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Abstract: This study evaluates the environmental sustainability of the municipality of Palmira, Colombia, using the emergy accounting approach. It provides an updated assessment of the territory's social-ecological metabolism for 2023 and offers a quantitative basis for planning in intermediate agro-industrial cities. The research is motivated by the increasing pressure that urbanization, agro-industrial expansion, and metropolitan integration place on the natural resources of intermediate municipalities, whose sustainability depends on the balance between the local ecological base and socioeconomic demands. In this context, the objective of the study is to evaluate the environmental performance of Palmira's territorial system using emergy indicators that integrate ecological and economic flows.

The methodology is based on Odum's emergy accounting framework. The system boundary was defined as the municipal territory of Palmira, and the main flows of energy, materials, food, goods, services, and economic transactions were identified. A system flow diagram was developed to represent these interactions. Physical and economic data for 2023 were obtained from official statistical sources and converted into solar emergy units (seJ) using emergy transformities reported in the scientific literature.

The results show a total emergy use of 3.20×10^{22} seJ/year, of which 41% corresponds to renewable resources, 34% to local non-renewable resources, and 25% to imports. The calculated indicators were EYR = 4.0, ELR = 1.44, and ESI = 2.78. These values suggest that Palmira has a relatively strong contribution from local resources and a moderate environmental loading level.



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The study concludes that Palmira operates as an agro-industrial social-ecological system with a significant ecological base supporting its territorial metabolism. However, dependence on external inputs and soil degradation remain important challenges for its long-term sustainability.

Keywords: energy accounting; territorial sustainability; urban metabolism; agro-industrial systems; intermediate cities; environmental performance; social-ecological systems.

基于能值分析的哥伦比亚帕尔米拉市区域可持续性评估

摘要：

本研究采用能值核算方法，评估哥伦比亚帕尔米拉市的环境可持续性。研究对该地区 2023 年的社会-生态代谢进行了更新评估，并为中等规模农工城市的规划提供了量化依据。本研究的出发点在于，城市化、农工产业扩张以及大都市一体化正在对中等规模市镇的自然资源造成日益增加的压力，而这些地区的可持续性取决于地方生态基础与社会经济需求之间的平衡。在此背景下，本研究旨在利用能够整合生态流与经济流的能值指标，评估帕尔米拉市域系统的环境绩效。

本研究的方法基于 Odum 的能值核算框架。研究将系统边界界定为帕尔米拉市行政区域，并识别了能源、材料、食物、商品、服务和经济交易等主要流动。为表示这些相互作用，研究构建了系统流图。2023 年的物理数据和经济数据来自官方统计来源，并使用科学文献中报告的能值转换率，将其转换为太阳能值单位 (seJ)。

研究结果表明，帕尔米拉市的总能值使用量为 3.20×10^{22} seJ/年，其中 41% 来自可再生资源，34% 来自地方不可再生资源，25% 来自进口。计算得到的指标为：能值产出率 $EYR = 4.0$ ，环境负载率 $ELR = 1.44$ ，能值可持续性指数 $ESI = 2.78$ 。这些数值表明，帕尔米拉市具有相对较强的地方资源贡献，并处于中等环境负载水平。

本研究认为，帕尔米拉市作为一个农工型社会-生态系统运行，其区域代谢得到了重要生态基础的支撑。然而，对外部投入的依赖以及土壤退化仍然是其长期可持续发展面临的重要挑战。

关键词：

能值核算；区域可持续性；城市代谢；农工系统；中等规模城市；环境绩效；社会-生态系统。

1. Introduction

The rapid urbanization process that Colombia has experienced in recent decades has profoundly transformed the country's territorial structure and diminished the strategic role of intermediate municipalities within regional urban systems. According to the National Administrative Department of Statistics (DANE) [1], more than 77% of the Colombian population currently resides in urban areas, and a growing portion of this growth is concentrated in intermediate cities that act as hubs connecting rural areas with large metropolitan areas. Various studies on sustainable urbanization indicate that, as large cities

reach high levels of population density and pressure on natural resources, they progressively exceed their environmental carrying capacity, generating processes of territorial redistribution of population, infrastructure, services, and economic activities toward nearby municipalities [2]. In this context, intermediate municipalities emerge as key territories for understanding the new dynamics of urban sustainability, as they assume territorial support functions for metropolitan areas.

2. Territorial sustainability and socio-ecological systems

This phenomenon is particularly evident in southwestern Colombia, where the urban system formed by Cali, Palmira, Yumbo, and Jamundí functions as an expanding metropolitan corridor. Cali, with a population exceeding 2.5 million, is the main economic and urban center of the Valle del Cauca region, but its urban sprawl and growing resource demands have intensified environmental and territorial pressures on neighboring municipalities. In this context, the municipality of Palmira, with a population of approximately 375,000, has acquired a strategic role as an emerging intermediate city that absorbs some of the demographic, industrial, logistical, and service dynamics associated with the metropolitan area. As a result, its territory is undergoing significant transformations in land use, energy and material consumption, regional mobility, and the interactions between urban systems and ecosystems.

Therefore, analyzing the environmental and metabolic performance of the Palmira territory is fundamental to understanding how intermediate municipalities assume new roles within regional urban systems. In this sense, sustainability assessment using comprehensive approaches, such as emergy analysis, initially developed by Odum in 1996, is crucial [3] and later expanded by Brown & Ulgiati in 2004 [4], [5]. It allows for the identification and quantification of energy and material flows that sustain socio-ecological systems. This approach provides a robust foundation for assessing the sustainability of emerging urban economies, contributing key inputs for territorial planning, environmental management, and the design of more resilient development strategies in Colombia's intermediate cities.

Currently, territorial environmental sustainability is a central research focus in environmental sciences, ecological economics, and urban planning. Territories are complex socio-ecological systems that interact to determine the system's capacity to sustain human well-being without compromising the integrity of ecosystems [6]. In this context, assessing sustainability involves understanding not only the visible economic and material flows, but also the biophysical foundations that underpin human activities.

Urban and agricultural growth, along with globalization, increase pressure on natural resources, creating an imbalance between the carrying capacity of ecosystems and the demands of human societies [7]. For this reason, methodologies have been developed to assess territorial sustainability, including the ecological footprint, urban metabolism analysis, life cycle analysis, and emergy analysis. Of these, emergy analysis has gained increasing relevance due to its ability to integrate into a single metric the flows of energy, materials, and ecosystem services that sustain socioeconomic systems, allowing the evaluation of the

relationship between the economy and the biosphere from a thermodynamic and systemic perspective. [8].

2.1 Conceptual foundations of emergy analysis

The concept of emergy is defined as the total amount of available energy of a specific type, usually solar energy, that has been required directly and indirectly to produce a resource, product, or service. It was developed by ecologist Howard T. Odum as an environmental accounting tool based on the principles of thermodynamics and systems theory [3].

In other words, emergy represents the energy memory of the natural and economic processes that have contributed to the generation of a good or service. To express these flows in a common unit, emergy analysis uses the unit called the solar emergy joule (solar emergy joule, sej).

The main advantage of this approach lies in its ability to integrate resources of diverse nature, including: renewable energy (solar radiation, wind, rain), natural resources (soil, water, biomass), non-renewable resources (fossil fuels, minerals), and economic goods and services. In this way, emergy analysis allows for the comparison and addition of heterogeneous flows that are difficult to integrate in other methodologies.

2.2.1 Transformivity and emergent accounting

A central element in emergy analysis is the concept of transformivity. Transformivity represents the amount of solar emergy needed to generate one unit of energy or mass of a given resource. Mathematically, it is expressed as:

$$\text{Transformivity} = \frac{\text{Emergy}}{\text{Energy}}$$

Transformivity reflects the degree of energy transformation required to produce a resource. In general, resources that have undergone multiple stages of transformation exhibit higher transformivity values. For example, solar energy has a low transformivity, whereas industrial products or economic services present significantly higher values.

Emergy accounting consists of identifying all the flows of energy and materials that enter a territorial system and converting them into emergy using transformivities previously established in the scientific literature. These transformivities have been compiled and updated in various studies, particularly by Brown and Ulgiati. [4, 5, 8], who have developed reference tables widely used in sustainability studies.

2.2 Importance of Emergy Analysis for Territorial Planning

Emergy analysis provides an integrated perspective for territorial planning by incorporating ecological and economic dimensions into a common analytical framework. By quantifying the contribution of natural resources to human activities, this approach makes it

possible to recognize the value of ecosystem services that are often not considered in traditional economic assessments.

Furthermore, energy analysis provides relevant information for the design of public policies aimed at promoting territorial sustainability by identifying the main resource flows that sustain the socioeconomic metabolism of territories.

In this sense, energy analysis has become a robust tool for evaluating the sustainability of territorial systems and supporting planning processes oriented toward a more efficient and responsible management of natural resources.

3. Methodology

The sustainability of the municipality of Palmira was evaluated using the energy accounting methodology, originally developed by Howard T. Odum, by quantifying all forms of energy, materials, and services that sustain a socio-ecological system and expressing them in a common unit known as solar energy joules (seJ).

Energy represents the total amount of available energy of a given type (generally solar energy) that is required directly and indirectly to generate a product, service, or process. This approach allows the integration of ecological and economic flows within a unified accounting framework, making it suitable for evaluating the sustainability of territorial systems.

The energy evaluation followed the methodological procedures commonly used in territorial and urban metabolism studies [3, 4, 9]. The methodological process consisted of the following steps:

1. Definition of the system boundaries corresponding to the administrative territory of the municipality of Palmira, Colombia.
2. Identification of the main environmental and economic flows entering, leaving, and circulating within the system.
3. Construction of the energy system diagram representing the interactions between renewable resources, local non-renewable resources, imported inputs, and exported products.
4. Compilation of physical flow data (mass, energy, monetary flows, and services) from official statistical sources.
5. Conversion of all flows into solar energy units (seJ) using the appropriate transformities obtained from the literature (seJ/unit).
6. Calculation of energy indicators to evaluate the environmental performance and sustainability of the system.

3.1 Energy baseline and transformities

The selection of transformity coefficients followed a hierarchical and consistency-based approach in order to ensure methodological transparency and reproducibility.

First, priority was given to standardized transformity values reported in classical energy literature, particularly Odum (1996) [3], which provides foundational coefficients for primary environmental flows (solar radiation, wind, rainfall, and basic ecological processes). These values are widely accepted as reference benchmarks in energy accounting.

Second, for energy carriers, fuels, and industrial products, transformities were obtained from updated energy databases and studies such as Campbell et al. (2005), Sweeney et al. (2007) and Bastianoni et al. (2009) [9, 10, 11], which provide refined coefficients derived from empirical assessments and system-level evaluations. These sources are commonly used in contemporary energy studies due to their methodological rigor and expanded datasets.

Third, when multiple transformity values were available for a given flow, selection criteria were based on:

- (i) methodological compatibility with energy accounting standards,
- (ii) similarity of the production process to the studied system,
- (iii) recency and alignment with updated energy baselines.

All selected transformities were systematically adjusted to the updated global energy baseline of 12.0×10^{24} seJ/year proposed by Brown and Ulgiati (2016) [8], using proportional correction factors where necessary. This step ensures consistency across different data sources and comparability with recent energy studies.

For renewable environmental flows (wind, rainfall, river flows), transformities were assumed to be relatively stable across geographic contexts, following the assumption that these processes are governed by global biophysical dynamics. In contrast, for socio-economic and imported flows (fuels, goods, services), transformities reflect complex production chains and were selected from studies addressing global trade and industrial systems.

Although uncertainties may arise due to variability in transformity values reported in the literature, the use of widely accepted reference sources and the standardization to a common energy baseline reduce potential inconsistencies and improve the robustness of the results.

3.2 Classification of energy flows

Following standard energy accounting conventions, the flows entering the system were classified into three main categories:

Renewable resources (R):

Environmental inputs that are renewed in short ecological cycles, such as solar radiation, rainfall, and renewable biological production.

Local non-renewable resources (N):

Resources extracted from the territory that are not renewed on the timescale of human economic activity, including soil degradation, mineral extraction, and groundwater depletion.

Imported resources (F):

Energy, materials, food, fuels, electricity, and economic services entering the system from external regions. Exports (Ne) represent goods and services leaving the system boundary and transferring energy to other territories.

3.4 Data sources

The physical and socioeconomic data used to construct Table 2 of the energy accounting (Appendix A) were obtained from official and institutional statistical sources at the national, regional, and local levels for the year 2023.

Primary data sources include government agencies such as the National Administrative Department of Statistics (DANE), the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), the Mining and Energy Planning Unit (UPME), and the Central Bank of Colombia, as well as sectoral reports from organizations related to agriculture, energy production, and infrastructure. These sources provide reliable information on population, economic activity

(GDP), energy consumption, agricultural production, material use, and environmental variables such as solar radiation, precipitation, and hydrological flows.

The estimation of system flows followed a structured procedure. First, the raw statistical data were collected in their original units (e.g., kg/year, m³/year, kWh/year, USD/year). Second, these values were converted to energy units (J/year) using appropriate physical conversion factors, such as calorific values, energy densities, or standard thermodynamic coefficients, depending on the nature of each flow. For example, agricultural and food products were converted using calorific content, fuels using energy content per unit mass or volume, and hydrological flows using potential or chemical energy equations.

Third, the resulting energy values were converted to solar energy units (seJ) by applying the corresponding transformity coefficients obtained from the literature, as described in Section 3.1. This step allowed for the integration of heterogeneous flows (environmental, material, and economic) into a unified accounting framework.

The detailed calculation procedures, including formulas, assumptions, and data sources for each flow, are presented in Appendix A. This ensures the transparency and reproducibility of the energy accounting process, allowing other researchers to replicate or adapt the methodology to similar territorial systems.

3.3 Energy indicators

Based on the calculated energy flows, several performance indicators were estimated to evaluate the environmental sustainability of the territorial system of the municipality of Palmira. The main indicators used in this study are presented in Table 1.

Table 1. Indicators for the evaluation of environmental performance

Indicator	Formula	Units	Description
Total Energy	$Y = R + N + F$ where: N represents non-renewable resources F economic resources, R renewable resources.	seJ/year	Total energy supporting the system
Energy Yield Ratio	$EYR = \frac{Y}{F}$ where: Y total energy of the system F energy of imported economic resources..		This indicator measures the system's capacity to exploit local resources and generate energy in relation to imported inputs.

Environmental Load Ratio

$$ELR = \frac{N + F}{R}$$

where:

N represents non-renewable resources
F represents economic resources
R represents renewable resources.

This index represents the pressure exerted by economic activities on the environment.

Energía Sustainability Index

$$ESI = \frac{EYR}{ELR}$$

This indicator assesses the balance between resource exploitation and environmental stress, providing an integrated measure of sustainability. In addition, indicators of energy intensity, such as per capita energy and energy density, were calculated to evaluate the metabolic intensity of the municipal economy.

Renewable Energy Captured Index

$$R/F$$

Index of effectiveness of the socioeconomic system in capturing natural flows.

Emergy consumption per person

$$Y/Population$$

sej/person/year

Measure of the average potential standard of living of a population

Renewable Load Capacity

$$Y/Territorial\ area$$

sej/m²/year

Pressure index of a process on a territory.

Renewable charging capacity

$$(R/Y) \times Population$$

Population

It estimates the population that could be sustained by relying solely on renewable resources.

Emergetic Monetary Index

$$Y/GDP$$

sej/\$

Relates emerging market to monetary units. Analysis of trade relations.

where:

Y emergy total
GDP gross domestic product

4. Results and Discussions

4.1 System boundaries of the municipality of Palmira

The system boundaries correspond to the administrative territory of the municipality of Palmira, located in the department of Valle del Cauca in southwestern Colombia, as shown in **Figure 1**. The municipality is situated in the inter-Andean valley of the Cauca River basin and forms part of the metropolitan area of influence of the city of Cali.

The municipal territory extends approximately between 3°27' and 3°37' north latitude and 76°07' and 76°25' west longitude, covering an area of approximately 1,162 km², which includes both urban and rural zones. This spatial delimitation was adopted as the system boundary in order to encompass the full set of ecological and socioeconomic processes that sustain the municipal metabolism.

Hydrologically, the municipality is located in the upper basin of the Cauca River, which constitutes the main regional drainage system. Within the municipal

territory there are several important tributaries and sub-basins, including the Amaime and Bolo river basins, which originate on the western slopes of the Central Cordillera and drain into the Cauca River.



Figure 1. Location of the municipality of Palmira, Valle del Cauca, Colombia

4.2 Identification of the main environmental and economic flows

To define the municipality of Palmira as an ecological system, it was necessary to identify and characterize the rural and urban components that integrate the territory within a system flow diagram. Based on this representation, the inflows and outflows of energy were established and identified with the greatest possible specificity for subsequent quantification, as well as the relationships between system components and the surrounding environment. Information from various sources related to both rural and urban components was compiled to schematize these interactions using the symbols of systems ecology [3]. The interactions of the ecosystem with energy inputs and outputs can be observed in Figure 2.

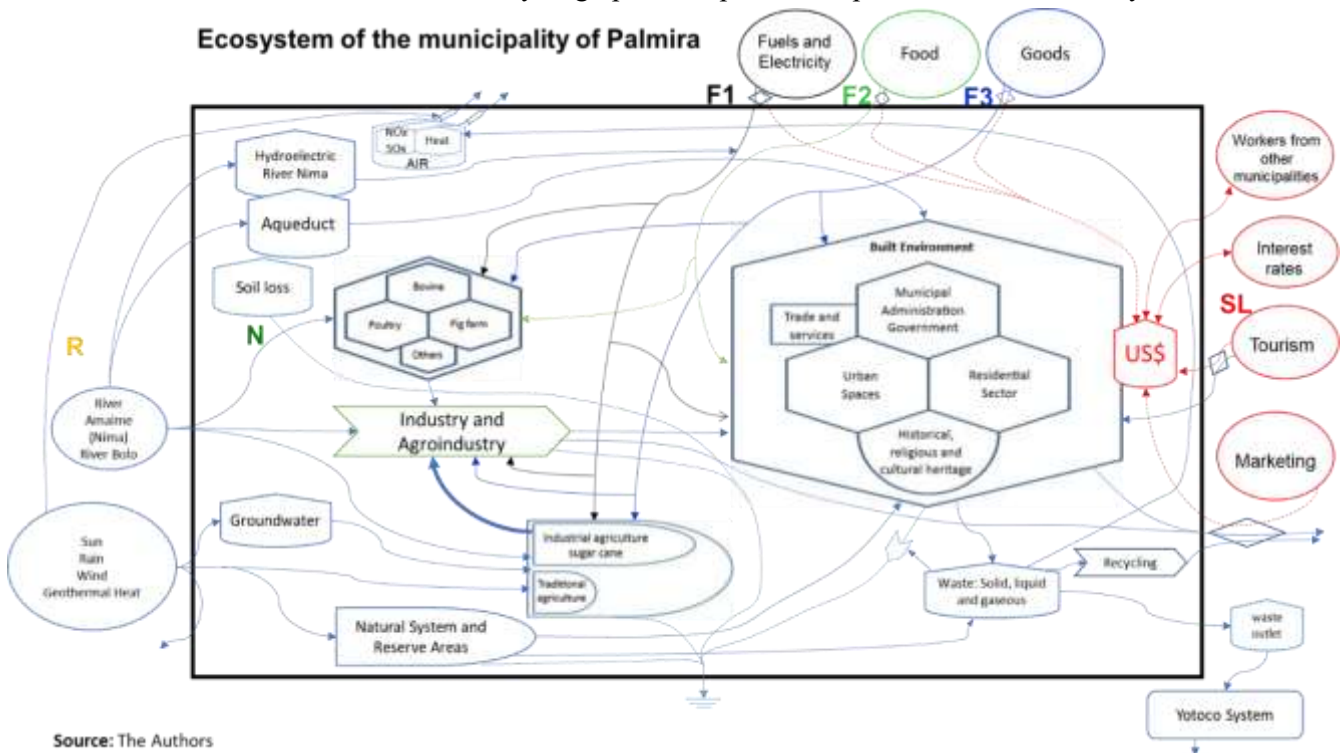
Based on a previous study conducted in 2013 [9], the system diagram was updated for the year 2023. This updated diagram allows the identification of the main characteristics of the system and facilitates the understanding of the society–nature relationship through the interaction between its environmental and anthropogenic subsystems. Its structure is organized from left to right, following the increasing value of transformity, which allows a progressive representation of the biophysical components of the territory and the economic sectors that make up the socioecological system. Likewise, the diagram illustrates the interactions among these components, represented through material pathways and exchanged energy flows, providing a preliminary view of the internal complexity and metabolic dynamics of the territory.

The territorial system is influenced by the Amaime and Bolo river basins. Within this hydrographic

context, an urban system develops that demands various goods and services to meet the needs of a population of approximately 375,394 inhabitants. The productive structure of the municipality shows a marked predominance of the agricultural sector, particularly sugarcane cultivation, whose associated agroindustry includes the production of sugar, bioethanol, and biomass. In addition, other food crops and productive activities linked to the agroindustrial system and the supply of the regional market are developed. The industrial and livestock sectors also interact within this system, supplying goods for urban consumption while contributing to exports, economic transactions, and employment generation.

Several mechanisms for the use and storage of renewable energy stand out within the system, including three small hydroelectric power plants, a solar park, and the energy utilization of biomass. These local energy sources are integrated into the system together with imported flows of electricity and fuels from other territories, forming the energy base that supports productive activities and the functioning of the urban system.

Likewise, the system incorporates components associated with the provision of environmental services and the dynamics of natural resources, such as water supply through the aqueduct system, soil loss associated with productive processes, and the atmospheric component. These elements depend fundamentally on the flows of renewable resources entering the system, among which solar radiation, precipitation, wind, and thermal energy flows are particularly notable, as they sustain the ecological and productive processes of the territory.



Source: The Authors

Figure 2. Energy flow diagram of the Palmira municipality system 2023

Due to the complexity of the system, imported energy flows were differentiated using a color-coding scheme to facilitate their interpretation within the diagram. The black color represents flows associated with fuels and electricity (F1); green corresponds to imported food (F2); blue identifies goods and services originating from other territories (F3); and red represents monetary flows or economic exchanges (SL).

At the bottom are shown the emergency drains as well as the transport of waste to the ecological system of the municipality of Yotoco where the Colomba-El Guabal controlled landfill is located.

This distinction allows for a clearer understanding of how different external inputs enter the territorial system. Specifically, it shows that the flows of food, goods, and services enter both the agricultural sector and the urban system directly, where they are transformed and used to sustain productive activities, population consumption, and the overall functioning of the municipality's socioeconomic system.

4.3 Conversion of all flows into solar energy units

The emergy table presents the main energy and material flows that support the territorial system, along with their respective transformivities and the equivalent in emergy, expressed in solar emergy units (seJ), as shown in Table 2. These flows were organized into different categories in order to represent in a structured way the socio-ecological metabolism of the territory.

Table 2. Energy flow table Palmira system 2023

Table 2 includes the transformivity values used in the emergy conversion process, along with their corresponding bibliographic sources. When multiple sources reported different values for the same flow, the selected transformivity corresponds to the most methodologically consistent and widely used value in emergy literature.

Item	United	Net Quantity	Transformity (seJ/unit)	Source Transformity	Emergy (seJ/año)
Renewable Resources					
1 Solar Radiation	J/year	6,87E+18	1	[3]	6,87E+18
2 Wind Speed (Kinetic Energy)	J/year	2,08E+17	1,50E+03	[9]	3,12E+20
3 Rain (Chemical Potential)	J/year	6,20E+15	3,10E+04		1,92E+20
4 Rain Geopotential	J/year	5,53E+15	1,80E+04		9,96E+19
5 Geothermal Heat	J/year	1,16E+15	1,20E+04		1,40E+19
6 River Flow	J/year	1,67E+15	2,80E+04		4,67E+19
Renewable Energy Production					
7 Hydroelectricity	J/year	3,96E+14	4,70E+04		1,86E+19
8 Electricity from Biomass	J/year	9,00E+14	2,00E+05		1,80E+20
9 Photovoltaic Electricity	J/year	1,76E+14	2,50E+05		4,40E+19
10 Ethanol	J/year	1,83E+15	6,60E+04	[3], [9]	1,21E+20
11 Meat	J/year	3,00E+14	4,50E+06		1,35E+21
12 Fish	J/year	2,50E+12	2,20E+06		5,50E+18
13 Fruits and Vegetables	J/year	5,86E+13	8,50E+05		1,19E+19

In particular, the flows were classified into the following categories:

- **Renewable resources**, which correspond to energy inputs derived from natural environmental processes, such as solar radiation, precipitation, and other ecological flows that are continuously regenerated.

- **Renewable energy production**, which includes energy generated within the territory from renewable sources such as biomass, hydroelectric energy, and solar energy.

- **Local non-renewable resources**, which correspond to resources extracted from the territory whose regeneration occurs on geological time scales, such as soil loss or the extraction of materials.

- **Imports**, which include flows of energy, food, goods, services, and fuels entering the system from other territories to sustain productive activities and population consumption.

- **National and international exports**, which represent goods and services produced within the territory and transferred to other economic systems.

This classification makes it possible to identify the relative contribution of local and external resources to the functioning of the system, as well as to evaluate the degree of dependence of the territory on imported flows and its capacity to generate emergy from its own resources.

Item	United	Net Quantity	Transformity (seJ/unit)	Source Transformity	Emery (seJ/año)
14 Sugar	J/year	9,44E+15	1,10E+06		1,04E+22
15 Grains	J/year	1,50E+14	1,20E+06		1,80E+20
16 Milk	J/year	5,94E+13	1,60E+06		9,50E+19
17 Tap Water Supply	J/year	7,05E+13	1,10E+05		7,75E+18
Local Non-Renewable Resources					
18 Soil Loss	J/year	9,56E+14	7,40E+04		7,08E+19
19 Sand and Gravel	g/year	3,80E+11	1,00E+09	[3], [11]	3,80E+20
Imported Emery					
20 Hydroelectricity	J/year	6,20E+13	4,70E+04	[10]	2,91E+18
21 Coal	J/year	2,33E+15	2,70E+04	[11]	6,29E+19
22 Gasoline	J/year	3,28E+15	1,11E+05		3,64E+20
23 Diesel	J/year	3,13E+15	1,11E+05		3,48E+20
24 LPG	J/year	2,06E+14	9,80E+04		2,02E+19
25 Natural Gas	J/year	3,27E+15	4,80E+04		1,57E+20
26 Cereals and Grains	J/year	1,04E+15	1,20E+06		1,25E+21
27 Oil	J/year	4,11E+14	1,80E+06		7,40E+20
28 Fruits and Vegetables	J/year	4,65E+13	8,50E+05		3,96E+19
23 Alcoholic Beverages	J/year	5,41E+12	2,80E+06		1,52E+19
30 Meat	J/year	1,76E+14	4,50E+06		7,91E+20
31 Fish	J/year	1,13E+13	2,20E+06		2,48E+19
32 Milk	J/year	6,49E+10	1,60E+06		1,04E+17
33 Wood	J/year	3,46E+14	3,40E+05		1,18E+20
34 Cement	g/year	1,15E+11	1,70E+09		1,96E+20
35 Limestone	g/year	1,95E+11	1,20E+09		2,34E+20
36 Sand and Gravel	g/year	2,53E+11	1,00E+09		2,53E+20
37 Steel	g/year	2,42E+10	5,60E+09		1,36E+20
38 Plastics (PET, PP, PS)	g/year	1,11E+10	6,30E+09	[3], [10]	7,02E+19
39 Aluminum	g/year	2,79E+08	2,10E+10		5,85E+18
40 Copper	g/year	1,20E+07	1,10E+10		1,32E+17
41 Other Metals	g/year	1,86E+09	8,50E+09		1,58E+19
42 Paper and Cardboard	g/year	7,43E+09	3,50E+09		2,60E+19
43 Textiles	g/year	1,86E+09	6,50E+09		1,21E+19
44 Glass	g/year	2,79E+09	1,20E+09		3,34E+18
45 Rubber	g/year	9,29E+08	5,00E+09		4,64E+18
46 Asphalt	g/year	1,36E+10	6,20E+09		8,43E+19
47 Fertilizers	g/year	2,42E+10	3,80E+09		9,20E+19
48 Services Associated with Imports	\$/year	2,30E+09	1,30E+12		2,99E+21
49 Labor Imported from Other Municipalities	person/year	3,85E+04	4,20E+15		1,62E+20
50 Tourism	\$/year	9,20E+06	1,30E+12		1,20E+19
National and International Exports					
51 Agricultural Products (Sugar and Fertilizers)	J/year	2,41E+15	1,50E+06		3,62E+21
52 Ethanol (Manuelita)	J/year	1,93E+15	6,60E+04		1,28E+20
53 Agro-industrial Products (Citrus, Panela and Liquors)	J/year	1,18E+15	2,50E+06	[3], [9]	2,95E+21
54 Chemical Products	g/year	1,18E+11	8,50E+09		1,00E+21

Item	United	Net Quantity	Transformity (seJ/unit)	Source Transformity	Emergy (seJ/año)
55 Plastics and Rubber	g/year	1,45E+10	6,30E+09		9,14E+19
56 Wood Products	J/year	2,79E+13	3,40E+05		9,50E+18
57 Paper and Derivatives	g/year	7,20E+10	3,50E+09		2,52E+20
58 Machinery and Equipment	g/year	1,02E+08	8,40E+09		8,57E+17
59 Glass	g/year	1,12E+09	1,20E+09		1,34E+18
60 Aluminum Products	g/year	2,95E+09	2,10E+10		6,20E+19
61 Services and Other Economic Transactions	\$/year	1,80E+09	1,30E+12	[10]	2,34E+21
GDP	\$/year	3,33E+09			
Government Expenditure	\$/year	2,51E+08			

4.4 Calculation of emergy indicators to evaluate the environmental performance and sustainability of the system

Based on the emergy table, environmental performance and sustainability indicators were calculated, as shown in Table 3, which allow the evaluation of the relationship between natural resource use, economic activities, and the pressure exerted on the environmental system. These indicators synthesize the information contained in the emergy flows and enable the analysis of the metabolic functioning of the territory.

Among the main indicators used are the Emergy Yield Ratio (EYR), the Environmental Loading Ratio (ELR), and the Emergy Sustainability Index (ESI).

Additionally, complementary indicators such as emergy per capita and emergy density were calculated, which allow the analysis of the metabolic intensity of the territorial system in relation to the population and the surface area of the municipality. Taken together, these indicators provide an analytical basis for evaluating the environmental performance of the territory and its degree of sustainability from the perspective of emergy accounting.

The total emergy $Y=3.20 \times 10^{22}$ seJ/year represents the energy base that sustains the ecological system of the municipality of Palmira, including its population, local production, and external inputs. This indicates the presence of a strong biophysical base, as 41% of the emergy originates from local renewable resources, which is characteristic of territories located in the geographic valley of the Cauca River.

Table 3. Emergy Indicators Palmira 2023

Emergy Table Flows		Unit	Emergy Flow	%
R	Renewable Emergy	seJ/year	1,31E+22	41%
N	Local Non-Renewable Resources	seJ/year	1,09E+22	34%
Nn	Local Soil Loss	seJ/year	4,51E+20	1%
Ne	Directly Exported Products	seJ/year	1,05E+22	33%
F1	Imported Emergy of Fuels and Electricity	seJ/year	9,54E+20	3%
F2	Imported Food Emergy	seJ/year	2,82E+21	9%
F3	Imported Emergy of Goods and Commodities	seJ/year	1,25E+21	4%
SL _N	Non-Renewable Fraction (94%) of Imported Labor and Services	seJ/year	2,96E+21	9%
SL _R	Renewable Fraction (6%) of Imported Labor and Services	seJ/year	9,70E+18	0,03%
F	Imported Emergy	seJ/year	8,00E+21	25%
Y	Total Emergy	seJ/year	3,20E+22	100%
Performance Indicators				
Y _{LS} /GDP _m	Emergia/GDP _m	seJ/\$	9,63E+12	
Y _{LS} /GDP	Emergia/person	sej/person	8,5E+16	

A	Total Area	m ²	1,2E+09
Y _{LS} /A	Potential Density	sej/m ² /year	2,8E+13
EYR	Emergy Yield Ratio		4,00
ELR	Environmental Load Ratio		1,44
ESI	Emergy Sustainability Index		2,78
Y _{pal} /Y _{Col}	Emergy Palmira/Emergy Colombia	%	1,46%

However, the system also shows a significant dependence on external resources (25%), including flows of fuels and electricity (F1), imported food (F2), goods and commodities (F3), and labor-related services (SL). This pattern is typical of intermediate municipalities integrated into functional metropolitan economies, such as the regional system connecting Cali and Palmira.

4.4.1 Local resources and environmental pressure

Local non-renewable resources $N=1.09 \times 10^{22}$ seJ/year (34%), together with soil loss $N_n=4.51 \times 10^{20}$ seJ/year (1%), indicate that a significant fraction of the territorial metabolism is sustained by the depletion of natural capital. This is associated with agricultural degradation, material extraction, and production intensification, dynamics linked to agroindustrial monoculture, intensive use of external inputs, and soil erosion. Although soil loss represents only 1% of the total energy flow, its ecological significance is high because it reflects the irreversible degradation of the territory's natural capital.

4.4.2 Imports and external dependence

Total energy imports $F=8.04 \times 10^{21}$ seJ/year (25%) indicate that the territory's main external dependence is not primarily energetic but socioeconomic, particularly in services, economic transactions, and imported food. This suggests that the urban metabolism of Palmira operates as an agroindustrial node within a regional network, in which economic and commercial flows play a significant role.

4.4.3 Exports and regional productive role

Directly exported products represent $N_e=1.05 \times 10^{22}$ seJ/year (33%), indicating that the system functions as an emergy-exporting territory due to the sugarcane agroindustry, food production, and agroindustrial manufacturing. In other words, the municipality transfers a significant portion of its biophysical base to other territories, particularly to regional and national markets.

4.4.4 Environmental performance indicators

The Emergy Yield Ratio (EYR = 4.00) indicates that for each unit of imported emergy, the system generates nearly four units of total emergy, revealing that Palmira

has a strong production capacity based on local natural resources.

Environmental Load Ratio ELR=1.44 The value suggests that Palmira presents a relatively low environmental pressure, due to its availability of renewable resources and its ecosystem base.

The Emergy Sustainability Index (ESI=2.78) indicates that Palmira exhibits moderate territorial sustainability. This means that although the system maintains a relatively strong productive capacity and comparatively low environmental pressure, it does not reach high levels of sustainability. This condition is mainly due to the dependence on imports, the use of non-renewable resources, and soil degradation.

4.4.5 Energy intensity of the territory and emergy density

Emergy per capita ($Y_{LS}/P=8.5 \times 10^{16}$ seJ/person) reflects the metabolic consumption of the economic system per inhabitant. This value indicates a moderate level of urban metabolism, consistent with Palmira's character as an intermediate agro-industrial city.

Emergy density ($Y_{LS}/A=2.8 \times 10^{13}$ seJ/m²/year) is a value associated with intensive agricultural systems, dense urban areas, and agroindustrial activities, which significantly increase the emergy intensity per unit of surface area. This condition is related to high pressure per unit area, the intensification of urban and agricultural land use, and the need for strategic planning to prevent irreversible environmental degradation.

4.5 Discussion

The emergy-based assessment of Palmira reveals a metabolic structure characteristic of intermediate agro-industrial territories, where local ecological resources play a significant role in sustaining socioeconomic processes. However, a deeper interpretation of the emergy indicators provides more nuanced insights into the system's sustainability dynamics.

The Emergy Yield Ratio (EYR = 4.00) indicates that Palmira generates approximately four units of emergy for each unit of imported emergy, reflecting a strong capacity to amplify external inputs through the use of local resources. This value is higher than those

typically reported for large metropolitan systems, where EYR values often range between 1 and 2 due to high dependence on imported energy and materials [12, 13]. In contrast, similar or slightly lower values have been observed in agro-industrial regions and intermediate cities, where local renewable resources still play a relevant role in sustaining economic activities [14].

This suggests that Palmira maintains a relatively favorable metabolic structure, in which the local ecological base contributes significantly to production processes. However, this apparent efficiency must be interpreted cautiously, as it is partially supported by the use of local non-renewable resources, particularly soil depletion associated with intensive agricultural practices.

The Environmental Loading Ratio (ELR = 1.44) indicates a relatively low level of environmental pressure compared to highly industrialized urban systems, where ELR values are typically much higher due to intensive use of fossil fuels and industrial inputs [15]. In Palmira, the availability of renewable resources such as solar radiation, hydrological flows, and biomass contributes to maintaining a more balanced relationship between renewable and non-renewable energy inputs.

Nevertheless, the ELR value does not fully capture localized environmental degradation processes. In particular, soil loss—although representing a small fraction of total energy—has a disproportionately high ecological impact, as it reflects irreversible degradation of the natural capital supporting the agro-industrial system. This highlights a key limitation of aggregated indicators, which may underestimate critical environmental pressures at the local scale.

The Emergy Sustainability Index (ESI = 2.78) places Palmira within the range of moderately sustainable systems. According to emergy-based classification frameworks, ESI values between 1 and 5 indicate systems that maintain a balance between productive efficiency and environmental pressure, but do not achieve high levels of long-term sustainability. Comparable values have been reported in regions where agricultural, industrial, and urban activities coexist, generating mixed sustainability outcomes [15], [16].

In the case of Palmira, the moderate ESI value reflects a transitional condition: the system retains a strong ecological base, but increasing dependence on imported resources and ongoing environmental degradation processes may reduce its sustainability over time.

From a territorial planning perspective, these results suggest that Palmira operates as a hybrid socioecological system, combining characteristics of both resource-based and urban-industrial economies. This dual condition creates both opportunities and

risks. On one hand, the presence of renewable resources and agro-industrial productivity supports local economic resilience. On the other hand, the growing dependence on external inputs and the degradation of key ecological assets, such as soils, may undermine long-term sustainability.

Therefore, improving territorial sustainability requires not only maintaining the contribution of renewable resources, but also reducing reliance on non-renewable inputs and strengthening strategies for ecological conservation. Integrating emergy indicators into territorial planning could support more informed decision-making by explicitly linking resource use patterns with environmental performance.

These findings highlight the importance of complementing emergy indicators with spatial and process-based analyses to better capture localized environmental impacts.

4.5.1 Implications for territorial planning

The results based on the emergence offer relevant information for territorial planning and policy formulation in intermediate agro-industrial cities like Palmira.

First, the relatively high emergence yield index (ERI) indicates that the territory has a significant capacity to generate value from local resources. This suggests that agricultural development strategies should prioritize strengthening local production systems, particularly those based on renewable resources, such as agroecological production, biomass energy, and sustainable agriculture.

Second, the moderate environmental burden index (EBI) reflects a relatively balanced use of renewable and non-renewable resources. However, this condition should not be interpreted as a stable equilibrium, as ongoing processes such as soil degradation may increase environmental pressure in the future. Therefore, territorial planning policies should focus on preventing the depletion of natural capital, especially through soil conservation programs, sustainable land-use planning, and regulation of agro-industrial expansion.

Third, the moderate Ecosystem Sustainability Index (ESI) indicates that Palmira is in a transitional stage between resource-based sustainability and increasing dependence on external inputs. In this context, reducing dependence on imported energy, particularly fuels, industrial goods, and external services should be a strategic priority. This can be achieved by promoting local production chains, circular economy strategies, and the regional integration of resource flows.

Furthermore, the significant contribution of exports to the territorial system suggests that Palmira functions as a net exporter of ecosystems within the regional economy. While this reinforces its economic role, it also implies a transfer of local ecological resources to

external systems. From a sustainability perspective, this underscores the need to balance economic growth with the conservation of the ecological base.

Finally, integrating ecosystem indicators into territorial planning instruments could improve decision-making processes by providing a systemic understanding of the relationship between resource use, environmental pressure, and economic performance. These indicators can support the design of policies aimed at improving resource efficiency, reducing environmental impacts, and strengthening long-term sustainability.

Overall, the results suggest that territorial sustainability in Palmira depends on maintaining a balance between its ecological base and its socioeconomic dynamics, while transitioning toward more resilient and resource-efficient development pathways.

5. Conclusion

The emergy analysis of the municipality of Palmira shows that the territory functions as an agro-urban socioecological system, in which the local ecological base and agroindustrial activities play a fundamental role in the territorial metabolism. The results indicate that a significant proportion of the emergy used by the system originates from local renewable resources, mainly associated with the agricultural productivity of the geographic valley of the Cauca River. El índice de rendimiento emergético (EYR=4,0) indica que el territorio posee una capacidad significativa para generar valor emergético a partir de los recursos locales, característica común en sistemas productivos donde la agricultura y la agroindustria contribuyen de manera importante al funcionamiento socioeconómico. Por su parte, el índice de carga ambiental (ELR=1,44) sugiere una presión relativamente baja sobre los recursos renovables, reflejando la relevancia de la base ecológica del territorio.

The combination of these factors is reflected in an Emergy Sustainability Index (ESI = 2.78), indicating a moderate level of territorial sustainability. However, the presence of flows associated with the use of non-renewable resources and environmental degradation processes, such as the loss of agricultural soils, highlights significant challenges for the future sustainability of the system.

Declarations

Author Contributions

Conceptualization, I.D.L.V., L.A.V.M and F.F.F.D.; methodology, I.D.L.V., L.A.V.M and F.F.F.D; formal analysis I.D.L.V., F.F.F.D; data curation: L.A.V.M; writing-review and diting, I.D.L.V.

Data Availability Statement

The data presented in this study are available on request from the corresponding autor.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this manuscript. In addition, ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies, have been completely observed by the authors.

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Appendix A

The following table shows the calculations and estimates for the different energy flows of the system, as well as the sources from which the data were obtained.

SIGLA	Resource –Service	Fuente	FORMULA
	Renewable Resource		
1	Solar Radiation		
RS	Average multiannual solar radiation (kWh/m ² /year): 1642,5	[17]	
FC	Conversion factor (J/kWh): 3.6E06		
AT	Land area (m ²): 1.162E09		ES=RSxATxFC
ES	Total solar energy (J/year) 6,87E+18		
2	Wind Velocity		
Vv	Average multiannual wind velocity (m/s/day): 2,1		
D _{aire}	Air Density (kg/m ³): 1.225		
AT	Land area (m ²): 1.162E09	[18]	Ev=[0.5x(D _{aire} x Vv ³)]xATxT
T	Seconds in the year: 3,15E+07		
Ev	Wind energy (J/year): 2,08E+17		
3	Chemical Potential of Rain		
Eq	Rain chemical energy ΔG (J/kg): 4.94E03		
P _A	Annual precipitation (m/year): 1.35		
D _{H2O}	Water density (kg/m ³): 1000	[19]	PQ _{II} = AT x (F _{EV} x P _A) x D _{H2O} x Eq
F _{EV}	Evapotranspiration fraction: 0.8		
AT	Land area (m ²): 1,16E+09		
PQ_{II}	Chemical potential of rainfall (J/year): 2,08E+17		
4	Geopotential Energy of Rainfall		
AT	Land area (m ²): 1,16E+09		
Pc	Annual precipitation (m/year): 1.35		
Em	Average elevation (m): 1200	[19]	Gp _{II} = AT*Fs*Pc*Em*Gr*D _{H2O}
Fs	Surface runoff fraction: 0.30		
Gr	Gravity (m/s ²): 9.8		
D _{H2O}	Water density (kg/m ³): 1000		
Gp_{II}	Total energy (J/year): 5,53E+15		
5	Geothermal Heat		
D _{sub}	Subsurface depth (m): 3000		
T	Temperature at 3 km depth (°C): 80		
T _{amb}	Average ambient temperature (°C): 23		
λ	Thermal conductivity of soil λ (W/m ² °C): 1.67	[20]	$Q = \frac{\lambda \times (T_{amb} - T)}{D_{sub}}$
Q	Average heat flow (J/m ² /s): 3.1E2		$Q_g = Q \times T_s \times AT$
AT	Total Area (m ²): 1.16E09		$Q^*AT^*T_s \times Q^*AT^*T_s$
Qg	Geothermal Heat (J/year): 1,16E+15		
6	Chemical Potential of Rivers		
	Average annual discharge Amaime River (m ³ /s): 10.11		
	Average annual discharge Bolo River (m ³ /s): 0.59		
Q _{total}	Caudal Total 10.7		
D _{H2O}	Densidad del Agua Kg/m ³ 1000	[21]	EQR= QC_{Annual} * D_{H2O} * EP_{H2O}
Q _{annual}	Caudal anual m ³ /año 3.37E08		
EP _{H2O}	Energía Potencial del Agua ΔG J/Kg 4.94E03		
EQR	Total energy (J/year): 1,67E+15		
	Renewable Energy Production		
7	Hydroelectricity (J): 3,96E+14	[22]	
8	Biomass (J): 9,00E+14	[23]	
9	Solar (J): 1,76E+14	[23]	
10	Ethanol		
P _{C2H6O}	Ethanol production (kg/year): 6,15E+07		
PC _{C2H6O}	Heating value (kJ/kg): 2.97E04	[23]	E_{palmira} = P_{C2H6O} x PC_{C2H6O} x 1000
E _{C2H6O}	Total energy (J): 1,83E+15		
E_{palmira}	Total energy (J/year)		
11	Meat	[23]	
Mc	Meat consumption (kg/year): 3,00E+07		
FC	Conversion factor: 2,500 kcal/kg		Me = Mc x FC x 4.186J/kcal
Me	Total energy (J/year): 3,00E+14		
12	Fish	[24]	
F	Fish consumption (kg/año): 5,00E+05		
FC	Conversion factor: 1,100 kcal/kg		Fish = F x FC x 4.186J/kcal
Fish	Total energy (J/year): 2,50E+12		

SIGLA	Resource –Service	Fuente	FORMULA
13	Fruits and vegetables	[25]	
FV	Fruits and vegetables Consumption (kg/year): 2.8E+07		$FyV = FV \times FC \times 4.186J/kcal$
FC	Conversion factor: 500 kcal/kg		
FyV	Total energy (J/year): 5.86E+13		
14	Sugar	[25]	
Su	Sugar consumption (kg/year): 5,72E+08		$Sugar = Su \times FC \times 4.186J/kcal$
FC	Conversion factor: 3,940 kcal/kg		
Sugar	Total energy (J/year): 5.86E+13		
15	Grains (kg/year): 9,44E+15		
Gr	Grains consumption (kg/year): 1,0E+07		$Granos = Gr \times Fc \times 4.186J/kcal$
FC	Conversion factor: 3,500 kcal/kg		
Granos	Total energy (J/year): 1.5E+14		
16	Milk	[25]	
Ml	Milk consumption (kg/year): 2,27E+07		$Milk = Ml \times FC \times 4.186J/kcal$
FC	Conversion factor: 626 kcal/kg		
Milk	Total energy (J/year): 5,94E+13		
17	Aqueduct water	[26]	
C _{H2O}	Water consumption (m ³ /year) 1.69E+07		$E_{H2O} = [(C_{H2O} \times D_{H2O})/1000] \times 4.186 J/kcal$
D _{H2O}	Water density (g/m ³) 1.0E+06		
E _{H2O}	Total energy (J/year): 7,05E+13		
	Local Non-Renewable Resources		
18	Soil Loss	[27]	
MO	Total soil loss (g/year): 2.25E12		$EA=MO*MOp*FC*$
MOp	Organic matter lost (%): 2.5E-02		
FC	Energy content of organic matter (J/g): 1.7E04		
EA	Total energy (J/year): 9,56E+14		
19	Argra, Sand and Gravel		
	Consumption (g/year) 3,80E+11		
	Imported Energy		
20	H_{elec} Local hydropower share	[28]	
E _{elec}	Hydropower Consumption (kWh/year): 1,72E+07		$H_{elec} = E_{elec} \times FC$
FC	Conversion factor (J/kWh): 3.6E10+06 J		
	Energy (J/year): 6,20E+13		
21	Carbón	[29]	
Car	Annual coal consumption (kg/year): 9.7E07		$Eca=Car \times Fac$
Fac	Conversion factor (J/kg): 2.4E07		
Eca	Total energy (J): 2,33E+15		
22	Gasoline	World Bank Group	
Gas _{per}	Gasoline consumption (gallons/year): 2,52E+07		$Gas_o = Gas_{per} \times FAC$
FAC	Conversion factor (J/gal) 1.3E+08		
Gas _o	Total gasoline energy (J/year): 3,28E+15		
23	Diesel	World Bank Group	
Dies _{per}	Diesel consumption (gallons/year): 2,16E+07		$Dies = Dies_{per} \times FAC$
FAC	Conversion factor (J): 1,45E+08		
Dies	Total diesel energy (J/year): 3,13E+15		
24	LPG		
LPG _m	Consumption (Kg/year) 4.48E+06		$LPG = LPG_m \times FAC$
FAC	Conversion factor (J/kg) 4.6E+07		
LPG	Total LPG energy (J/year) 2,06E+14		
25	Natural Gas	[30]	
GAS _m	Total m ³ /year 8.4E+07		$GAS = GAS_m \times FC$
FC	Conversion factor (J/m ³) 3.89E+07		
GAS	Total gas energy (J/year) 3,27E+15		
	Food		
HAB	Population 375394		$Po = PoPER \times HAB$
26	Cerper Grain consumption (kg/person/year): 814,82		
Cer	Total grain consumption (kg/year): 6.94E+07		$Cer = Cerper \times HAB$
27	Acper Vegetable oil consumption (kg/person/year) 29.6	[24], [25]	
Ac	Total vegetable oil consumption (Kg/year) 1,11E+07		$Ac = Acper \times HAB$
Frut _{per}	Fruit consumption (kg/person/year) 40		$Frut = Frutper \times HAB$
Frut	Total fruit consumption (kg/year) 1,5E+07		
Veg _{per}	Vegetable consumption (kg/person/year) 22		$Veg = Veg_{per} \times HAB$
Veg	Total vegetable consumption (kg/year) 8,26E+06		
28	FruVeg Total fruits and vegetables consumption (kg/year) 2,33E+07		$FruVeg = Frut + Veg$
29	Alcoh_{per} Alcoholic beverages consumption (liters/person/year)	[23]	
Alcoh _v	Alcohol consumption (liters/year) 6,3		$Alcoh = [(Alcoh_{per} \times HAB \times Dalcoh)] \times 2,9E+06$
D _{alcoh}	Ethyl alcohol density (g/liter) 7,89E+02		

SIGLA	Resource –Service	Fuente	FORMULA
	Alcohol Alcoholic beverages consumption (J/year) 5,41E+12		
30 PoPER	Chicken consumption (kg/person/year): 23	DANE ⁱ FENAV ⁱⁱ FEDEGAN ⁱⁱⁱ	Po= PoPERxHABx1000
	Po Chicken consumption (g/year): 8,63E+09		
	Caper Beef consumption (kg/person/year): 16		Ca= CaperxHABx1000
	Ca Beef consumption (g/year) 6,01E+09		
	Ccerper Pork consumption (kg/person/year): 7,8	[23]	Ccer= Ccerper*HAB*1000
	Ccer Pork consumption (g/year): 2,93E+09		
	Car1 Total meat consumption (g/year) 1,76E+10		Car1=Po+Ca+Ccer
	E _{car} Energy (J/year): 1,76E+14		E _{car} = (Car1/1000)*1E+07
31 Pezcar	Fish consumption (kg/person/year) 6		
	Pesc Fish consumption (g/year) 2,25E+09		Pesc= Pezcar*HAB*1000
	Epesc Energy (J/year): 1,13E+13		Epesc= Pesc x 1,100Kcal/kg x4.186 J/kcal
32 Lecper	Milk consumption (liters/person/year) 62	[23]	
	Lecv Milk consumption (liters/year) 2,33E07		Lec= Lecper*HAB* Dlec
	DLec Milk density (g/liter) 1,032		
	Lec Total milk consumption (g/year) 2,40e+07		E _{milk} = (Lec/1000)*2,70E+06
	E _{milk} Energy (J/year): 1,76E+14		
33	Wood		
	CoM Wood consumption (m ³ /year) 4.32E+04		
	Fac Conversion factor (J/m ³) 8.00E+09	[31]	ET=CoM x FaC
	ET Total energy in (J) 3,46E+14		
34 Cem_{pal}	Cement consumption (g/year) 1,15E+11		
35	Limestone (g/year) 1,95E+11		
36	Sand and gravel (g/year) 2,53E+11	[32], [33]	
37	Steel consumption (g/year) 2,42E+10		Ace=cpA*HAB*1000
38	Plastics (g/year) 1,11E+10		
39	Aluminum (g/year) 2,79E+08		
40	Copper (g/year) 1,20E+07		
41	Other metals (g/year) 1,86E+09		
42	Paper and cardboard (g/year) 7,43E+09	PGIRS ^{iv}	
43	Textiles (g/year) 1,86E+09		
44	Glass (g/year) 2,79E+09		
45	Rubber (g/year) 9,29E+08		
46	Asphalt (g/year) 1,36E+10		
47	Fertilizers (g/year) 2,42E+10		
48	Services associated with imports (US\$/year) 2,30E+09	[34]	
49	Labor imported from other municipalities (people/year) 3,85E+04	[34]	
50	Tourism (US\$/year) 9,20E+06	[34]	
	<u>National and International Exports</u>		
51	Agricultural Products (Sugar and Fertilizers)		
	ExA Exports Agricultural Products (g/year): 1,60E+11		
	Bio Energy from 1 g of Biomass (Kcal/g): 3.6	[23]	E _{ag} = ExA x Bio x FAC
	FAC Conversion Factor Joules: 4,19E+03		
	E _{ag} Energy (J/year): 2,41E+15		
52	Ethanol (Manuelita)	[23]	
	LC _{2H5OH} Ethanol Export (Liters/year): 9,13E+07		
	FC Conversion Factor in MJ/L: 2,12E+07		E _{C_{2H5OH}} = LC _{2H5OH} x FC
	EC _{2H5OH} Total Energy in Joules: 1,93E+15		
53	Agro-industrial Products (Citrus Fruits, Panela, and Liquors)	[23]	
	ExAg Export of agro-industrial products (g/year) 7,82E+10		E _{agroim} = ExAg x Bio
	Bio 1g Agro-industrial Products (J/g): 1,51E+04		
	E _{agroim} Total Energy (Joules) 1,18E+15		
54	Chemical Products (g/year) 1,18E+11		
55	Plastics and Rubber (g/year) 1,45E+10		
56	Wood Products		
	Wp Export Wood Products (g/year) 1,85E+09	[35]	
	Bio 1 g of Wood Point (J/g) 1,51E+04		E _{wood} = Wp x Bio
	E _{wood} Total Energy (Joules): 2,79E+13		
57	Paper and Paper Products (g/year) 7,20E+10		

ⁱ Departamento Administrativo Nacional de Estadística de Colombia (National Administrative Department of Statistics of Colombia)

ⁱⁱ Federación Nacional de Avicultores (National Federation of Poultry Farmers)

ⁱⁱⁱ Federación Nacional de Ganaderos de Colombia (National Federation of Livestock Farmers)

^{iv} Plan de Gestión Integral de Residuos Sólidos Palmira 2016-2030 (Comprehensive Solid Waste Management Plan)

SIGLA	Resource –Service	Fuente	FORMULA
58	Machinery and Equipment (g/year) 2,95E+09		
59	Glass (g/year) 1,12E+09		
60	Aluminum Products 2,95E+09		
61	Services and other economic transactions	[34]	
	GDP		
	Government expenditure (US\$/year)	[34]	