American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-12, pp-136-144
www.ajer.org
Research Paper Open Access

Application of emergy accounting techniques to the sustainability of the Ararangua River estuary

Oldemar de Oliveira Carvalho-Junior[1], Carla A. D'Aquino[2], Anwar Amine Sabbagh Junior[1], Alesandra Bez Birolo[1]
[1]Department of Energetic Modelling of Ecosystems, Ekko Brasil Institute, Florianópolis, Brazil, [2]Department of Energy and Sustainability (EES). Federal University of Santa Catarina, Araranguá, Brazil
Corresponding Author: Oldemar de Oliveira Carvalho Junior

***ABSTRACT** : In this study, emergy analysis is conducted to examine the natural physical foundation for the ecological organization of the Araranguá River estuary located in the southern part of the state of Santa Catarina, Brazil. The main objective of this study was to evaluate the emergy signature of renewable natural energy sources in the Araranguá River and determine their emergy inputs into the system. The energy model proposed for the study area is derived from a comprehensive account of the system under consideration, based on expert statements, bibliographic sources, and field studies. Subsequently, it is followed by the creation of an energy diagram of the system. Then, energy sources are evaluated and described, as well as energy stores and flows in the system. The environmental energy sources used to maintain the Araranguá River estuary system amount to 6.7 million emdollars per year, including the image. This work successfully utilized emergy analysis, which allowed the determination of the main energy sources that maintain the structure of the Araranguá River estuary. This can be beneficial for decision-making and the development of public policies, such as the allocation of resources and conservation tactics.*

***KEYWORDS:** Ecosystem modelling; Environmental Management; Emergy Assessment.*

Date of Submission: 12-12-2024 Date of acceptance: 25-12-2024

I. INTRODUCTION

The Araranguá River represents an estuary, with a length of 7 km, formed by the junction of the Itoupava and Mãe Luzia rivers, and an average annual flow of 1.67E+09 m^3 (Fig. 1). The estuary area is 4.63E+06 m^2, inserted into a basin with 3.02E+09 m^2, where 14 municipalities are located: Araranguá, Criciúma, Ermo, Forquilhinha, Içara, Jacinto Machado, Maracajá, Meleiro, Morro Grande, Nova Venice, Siderópolis, Timbé do Sul, Treviso, and Turvo. The exploitation of rice, livestock, and coal mining, coupled with the expansion of human economic activity, has resulted in harm to the ecosystem, including the loss of soil and water, as well as environmental degradation, as documented by D'Aquino et al. (2010).

Fig. 1. Estuary of the Araranguá River, in the state of Santa Catarina, southern Brazil.

The rice cultivation area in the basin region reaches a total area of 4.27E+08 m^2 and can consume up to 6.41E+08 m^3 of water per year (Voltolini et al., 2002), which is equivalent to 63 million liters per hectare per year. The Araranguá River annually transports approximately 315,600 kg of sediment to the sea. The majority of these materials are deposited on the riverbed, in its lower course, resulting in periodic flooding and occasionally altering the course of the river. The average water depth is 7.5 meters, with a depth of 2.5 meters near the mouth (Manique et al., 2011). Tides in the adjacent coastal area rarely exceed 1 meter.

The low pH of the water in the estuary, estimated at approximately 5, is a result of mining, thereby affecting the sustainability of the natural environment and social development, which are heavily dependent on water resources. Viera-Romero (2024) also identified contrasts between the economic viability of shrimp farming in the Gulf of Guayaquil and its environmental impact, highlighting the intricate nature of the utilization of natural resources in areas that are susceptible to export development. Integrated management involves coordinating efforts across various sectors, including environmental protection, urban planning, agriculture, and tourism. By aligning these diverse interests, it becomes possible to develop policies and practices that balance conservation needs with sustainable development goals.

The ecological assessment of energy and materials metabolism holds significant importance in assessing the extent of human appropriation of energy and resources, as well as determining the ecological state of the system. This study is based on knowledge of the general theory of systems and ecology (Odum, 1983; Odum, 1994), applicable to all natural phenomena. The application of emergy analysis is well established for agricultural, urban, industrial and wetland ecosystems (Zhang et al., 2024). The authors also highlight the importance of the method for analyzing ecosystem dynamics associated with public policies, aiming at the sustainability of ecosystem services in the long term. The ability to evaluate energy, matter and information is important for assessing the sustainability of various types of systems, according to Amaral et al. (2016).

This methodology presents basic principles from the perspective of the principle of maximum power, the law of energy hierarchy, and the pulsating paradigm, in order to better understand and interpret the impermanent reality of systems, which is the result of the dynamics of the energy flow between the biotic and abiotic compartments of the system. The dynamic succession aspect of the system can be more effectively assessed by examining the energy transition between the various compartments, without being ensnared by an illusion of stability, thereby compromising the management of nature. Therefore, emergy can be used as a general accounting tool since the transformation of energy is present in all phenomena.

The second law of thermodynamics, also known as thermodynamic entropy, and the irreversible entropy of ecosystems, can be used to discuss the impermanent nature of the environment. It is a fundamental principle of physics that describes the natural direction of energy transfer processes. The second law of thermodynamics has significant implications for ecosystems. It suggests that natural systems are constantly evolving and changing, never remaining in the same state. This is consistent with the observation that ecosystems are dynamic and in constant flux, responding to internal and external disturbances. In this context, emergy facilitates the formulation of all phenomena on a common basis, thereby enabling comparison of the production of phenomena that appear to be distinct from human perception. Due to this innovative approach, which is capable of showing a more useful reality for long-term system's management, emergy analysis, and energy systems methods, it has been extensively documented elsewhere (Odum, 1994; Odum 1996; Patten, 2013).

The entropy of ecosystems is closely linked to the impermanent nature of the environment. This impermanence manifests itself in many forms, from seasonal changes to long-term transformations in the composition and structure of ecosystems. Ecological succession, for example, is a process that clearly demonstrates this dynamic nature. Global climate change is an example of environmental impermanence, since changes in the flows of energy and matter can cause major changes in ecosystems on a global scale. Understanding this changing nature is crucial to developing effective conservation and environmental management strategies.

Emergy analysis considers not only the energy directly used in a process, but all the energy required to produce the inputs to that process as well. This includes solar, geothermal, and tidal energy that has transformed over time to create the resources used. This holistic approach allows for a deeper understanding of the true costs and sustainability of ecological and human processes. Therefore, emergy is the available energy, previously used to carry out a process, that can be used to manufacture a new product or service.

Emergy has the capability to utilize any type of energy as a common base, including but not limited to coal joules and solar joules. However, when evaluating environmental systems, solar energy is used as a base unit. The term "solar emergy" refers to the readily available solar energy utilized to produce a product or service within an ecological or economic framework (solar emjoule, seJ). Therefore, the available energy is the energy capable of doing work, also called exergy. Another commonly used term is empower, the emergy flow per unit of time, in addition to empower density, the emergy flow per unit area.

The emergy method, proposed by Odum, is important for providing a system for quantifying alternative values, which provides an objective measure of the ecological and economic costs and benefits of carrying out a given process. In this study, we examine the natural physical basis for the ecological organization of the Araranguá River estuary in the south of the state of Santa Catarina, Brazil. The main objective of this study was to evaluate the emergy signature of renewable natural energy sources in the Araranguá River and determine their emergy inputs into the system.

II. METHOD

The energy model proposed for the study area was prepared based on a detailed description of the system in question, as well as expert statements, bibliographic sources, and field studies. Upon conducting this analysis, a comprehensive energy diagram is generated, encompassing all known components and processes of the system. The initial step involves aggregating all comparable components and procedures, thereby enabling the model to be disaggregated as required, and address a specific inquiry.

The objective is to understand the interrelationships between the main components of the system and the processes that regulate energy flows in the study area. The diagram provides a comprehensive view of the system, integrating various sources of information and coordinating research planning, analysis and data synthesis. This study aims to evaluate the environmental viability of the estuary through an assessment of renewable energy flows.

The diagram should visually represent the interconnections between these elements, showing how the flows of energy, materials, and information move through the system. This graphical representation serves as a valuable tool for understanding the complexity of the system and identifying key points for intervention or study.

Once the energy diagram is complete, the next step is to prepare a spreadsheet to calculate energy flows. This spreadsheet uses the diagram as a reference and accounts for the annual flows of material, energy, and information that support the estuary. Several energy sources are considered in the calculations, including sun, rain, wind, waves, tide, nitrogen, and phosphorous. The image and its importance are also analyzed. The spreadsheet organizes the complete energy flow sustaining the system into renewable resources.

Then, energy sources are evaluated and described, as well as energy stores and flows in the system. Using data obtained from academic literature on the study area (D'Aquino et al., 2010; Barreto, 2011; Manique et al., 2011; Valle-Levinson et al., 2019; Silvestre and D'Aquino, 2020), the ecological flows and energy signature of the system were determined.

The emergy stored in the system is calculated by adding the emergy of all inputs and multiplying it by the time it takes for them to accumulate. This time is estimated based on the available scientific literature. All the energy inputs needed to produce economic stocks are added together to calculate the total emergy. This calculation is essential for understanding the total amount of energy incorporated into the system over time, providing a more complete view of the sustainability and energy efficiency of the estuary. The stored emergy represents the accumulated energy investment in the system and is an important indicator of the resilience and carrying capacity of the study area.

III. RESULTS

Initially, an energy model of the system was developed for the emergy assessment of the Araranguá River estuary. The energy assessment model is built using the energy systems language, developed by Howard T. Odum (Odum, 1983; Odum, 1994). Systems language uses symbols with special meanings to represent the structure and function of the system. To develop an emergy assessment model, it is necessary to establish the limits of the system in question. In this study, the selected area is the water surface of the Araranguá River, which totals 875 thousand square meters (Figure 1). The emergy assessment model for the river estuary ecosystem is shown in Figure 2.

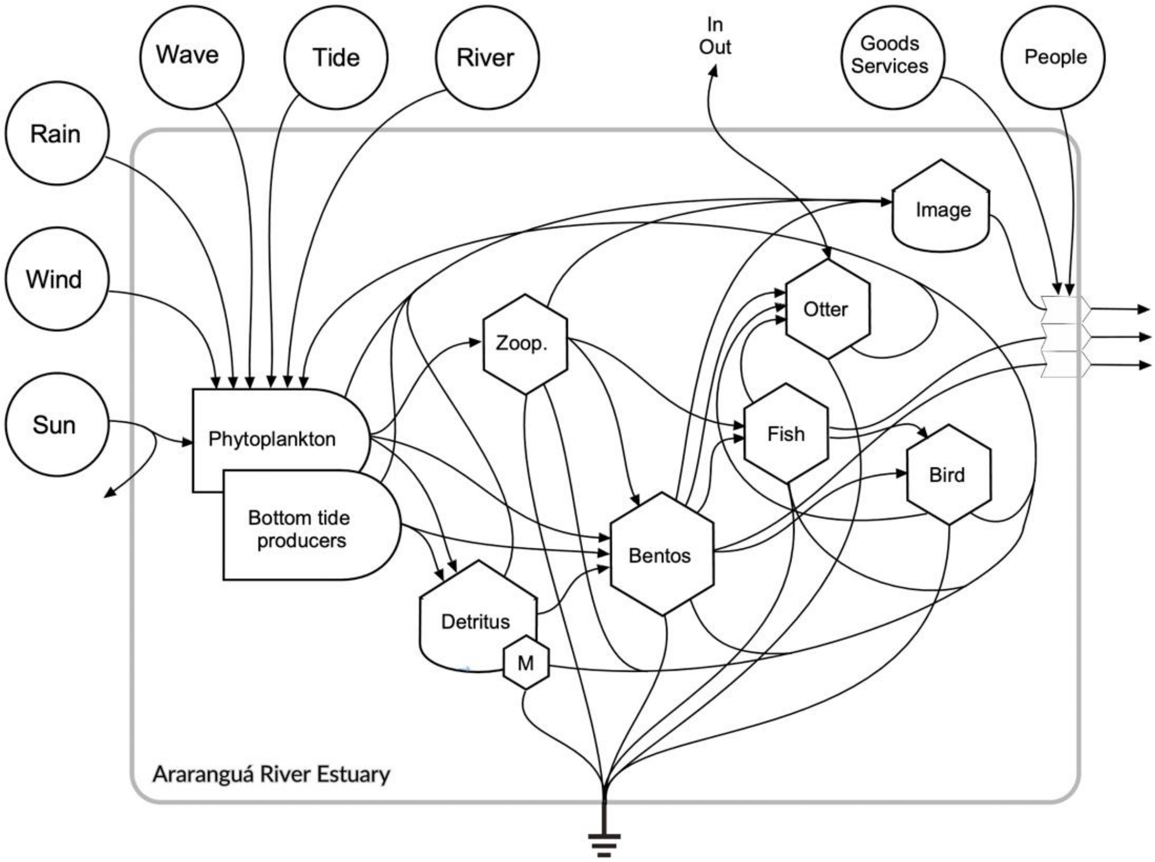

Fig. 2.Diagram of the energy system of the Araranguá River Estuary, Santa Catarina, Brazil. M=microorganisms. After Kang, 2013.

An emergy assessment table is created using the energy model (Tab. 1). It helps to quantify the various types of energy and resources that are used or produced within the Araranguá River estuary. The energy model refers to a set of equations used to calculate energy flows and transformations within a system. The Table displays an annotation number to indicate the evaluation item's emergy calculation process, the evaluated items, and the energetic values of each item, transformities, emergy values, and the monetary value of each one.

Tab. 1. Emergy contributions of the environmental sources that sustain the Araranguá River Estuary in Brazil.

Note[a]	Item	Raw data	Transformity (sej/J)	Solar Emergy seJ/yr
1	Sunlight	2,26E+16	1	2,26E+16
2	Wind	9,85E+11	2.450	2,41E+15
3	Rain, chemical	2,79E+13	30.500	8,50E+17
4	Wave	2,61E+07	51.000	1,33E+12
5	Tide	1,48E+12	73.900	1,09E+17
6	River, chemical	1,27E+14	81.300	1,03E+19
7	Mãe Luzia River, nitrogen	2,61E+04	4,19E+09	1,10E+14
8	Itoupava River, nitrogen	1,15E+05	4,19E+09	4,82E+14
9	Mãe Luzia River, phosphorous	8,29E+02	1,4E+10	1,16E+13
10	Itoupava River, phosphorous	1,78E+03	1,4E+10	2,50E+13
	Image			1,13E+19
	Total			1,13E+19

1. Sunlight Energy, J/yr = (Area) x (Insolation) x (1-albedo), Total area, m^2 = 4,63E+06, Insolation, J/m2/yr = 5,66E+09, Albedo = 0,14; 2. Wind(Energy, J/yr = (area) x (air density) x (drag coefficient) x (Geostrophic wind-average wind speed)^3 x (3,14 E+07), Average wind speed, m/s = 2,60, Air density, kg/m3 = 1,30, Drag coefficient = 0,001, Geostrophic wind = 4,33; 3. Rain, chemical Energy, J/yr = area x rain x density x Gibbs free energy, Rain, m/yr = 1,22, Gibbs free energy, J/kg = 4940, density, kg/m3 = 1000, 4. Wave Energy, J/yr = (shore length) x (1/8) x (density) x (wave height)^2 x (wave velocity), Shore length, m = 118000 (Camacho a Torres), Wave height, m = 0,20 (assumed), Depth, m = 8, Gravity, m/s2 = 9,8, Wave velocity, m/s = 8,85 ((gravity x depth)$^{1/2}$); 5. Tide Energy, J/yr = (Area) x (0,5) x (706) x (tidal height^2) x (1025) x (9,8), Average tidal height^2, m = 0,09; 6. River chemical Energy, J/yr = (Inflow1 + Inflow2) x (density) x (Gibbs free energy), Inflow Rio Itoupava, m^3/yr = 1,98E+10, Inflow Rio Mãe Luzia, m^3/yr = 6,37E+09, Gibbs free energy, J/kg = 4,73, density, kg/m3 = 1025.

Energy data is the data used to calculate the emergy of assessment items. The emergy table uses annual data, such as annual energy flow (J/year), material flow (g/year), and money flow ($/year or $R/year). The emvalue is the amount of solar emergy divided by the currency rate (GDP). Emvalue is a value that converts the amount of emergy into monetary units. This makes it possible to compare the results of the emergy assessment with the results of other methods that use monetary units. The financial value is the rate of the amount of energy used, by the value of the Brazilian economy in a year. It is obtained by dividing solar emergy (seJ/yr) by the annual gross domestic product (GDP 2023).

The total natural resources responsible for the maintenance and natural sustainability of the Araranguá River estuary are 6,7 million emdollars per year. The river chemical, which is the composition of elements and compounds present in river water, influenced by factors such as geology, climate, human activities, and hydrological processes, is the most valuable energy sources, accounting for a total of 3 million emdollars annually. They are followed by the rain chemical, accounting for 250 thousand emdollars annually. Apart from the natural resources, image is the highest economic value with 3,3 million emdollars. Fig. 3 illustrates the energy signature of the Araranguá River estuary, with logarithmic values to accommodate all items.

The range of values is dominated by the chemical energy of rivers, followed by precipitation, tidal action and radiation from the sun. Tides, winds, waves, and precipitation can be considered an energetic group, with peak energies acting in the range of 1.33E+12 to 1.60E+17 seJ/year. The energy peaks in this group demonstrate the relative capacity of each energy source to perform tasks within the system.

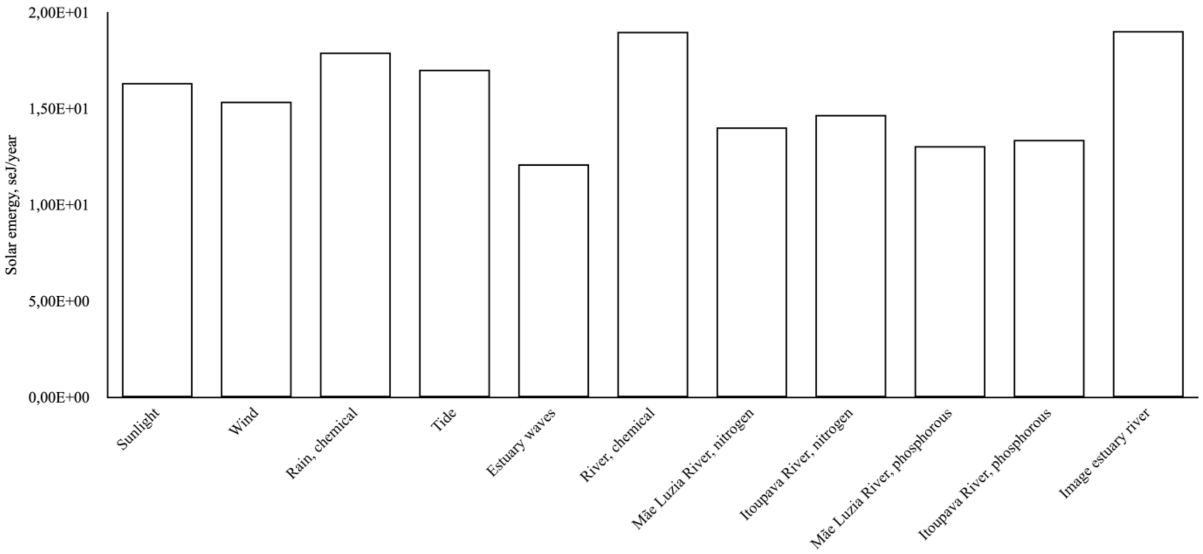

Figure 3. The energy signature of the estuary system of the Araranguá River, including its energy sources. The values are logarithmic. The energy values mentioned in the text are shown in Tab. 1.

The emergy signature reveals a second energy group, which corresponds to the nitrogen and phosphorus absorbed by the waters of the two principal rivers that comprise the Araranguá River. The emergy flux derived from nitrogen present in river water is significantly higher than that derived from phosphorus, ranging from 1.10E+14 to 4.82E+14 seJ/year. The emergy contribution in phosphorus varies from 1.16E+13 to 2.50E+13 seJ/year, in. The total nitrogen entering the estuary each year (1.41E+05 g/year) is supplied by the Mãe Luzia and Itoupava rivers. The highest emergy value obtained is that of the river (1.03E+19 seJ/year), followed by rain (8.50E+17 seJ/year), tide (1.09E+17 seJ/year), and wind (2,41E+15 seJ/year). The Araranguá River ecosystem receives energy inputs from tides, waves, winds, and chemical potential energy from freshwater (rivers and rain), nitrogen, and phosphorus.

The environmental energy sources used to maintain the Araranguá River estuary system amount to 6.7 million emdollars per year, including the image. To calculate the image value, all values from external energy sources are used. It is not surprising that this represents the highest financial value, at 3.3 million emdollars per year. The river, which is associated with the entry of the rivers Mãe Luzia and Itoupava, holds the second-highest monetary value in the system, with a value of 3 million emdollars per year. This is followed by rain (250 thousand emdollars per year) and tide (32 thousand emdollars per year).

IV. DISCUSSION

The assessment of the contribution of the ecosystem to the Araranguá River estuary, using the emergy methodology, was carried out from two systemic perspectives, economic and environmental. The contribution of the estuarine ecosystem was evaluated using the flow of energy or materials from the outside to the inside. To evaluate the contribution of the Araranguá estuary ecosystem to the maintenance of the natural system and, indirectly, to the economy (which was not considered here), natural environmental energy is supplied, excluding the amount of emergy generated by the economic system.

The values presented represent the environmental costs associated with the existence of the Araranguá River estuary system, from a scientific perspective. Although not addressed in detail in this study, economic activities in the Araranguá River estuary are also influenced by these energy sources. In the case of image valuation, the total amount of natural environmental emergy that flows into the Araranguá River estuary was used, and forms the scenario of the estuary ecosystem, appreciated by residents and tourists. Therefore, the scientific standpoint is confronted with the economic and tourist perspective in society.

The system's emergy signature indicates that the river (1.03E+19 seJ/year), precipitation (8.50E+17 seJ/year), and tides (1.09E+17 seJ/year) are the primary renewable energy sources that determine the environmental, meteorological, and oceanographic factors responsible for creating one of the most productive and beautiful areas of the Brazilian coast. The unique characteristics of the estuary contribute to their high ecological and economic importance. It is worth noting that the input of nitrogen and phosphorus into the estuary is calculated at 5.91E+14 seJ/year and 3.66E+13 seJ/year, respectively. It seems redundant to state that the river, rain, and tide are important in the dynamics of the system, considering that we are analyzing an estuarine system. It is essential to note that an economic value is established for the main environmental assets, in addition to defining a hierarchy of importance for these assets.

A previous study of the social perception of renewable energy in the study area revealed disparity in knowledge related to the sustainability of the coastal zone and renewable energy (D'Aquino and Peyerl, 2022). On the other hand, it indicates a general acceptance for the use of renewable energy sources, especially solar and wind. However, the study identified a lack of knowledge among the local population regarding sustainability and renewable energy sources. In another study that includes social perception, which examines a water conservation model based on ecotourism in the Ayung River estuary, Eryani and Jayantari (2019) emphasize the significance of involving local individuals in the long-term success of conservation and tourism initiatives. Environmental protection, cultural preservation and economic growth are public policies that should be carefully formulated. However, it is obvious to see that people's distance from physical reality can be an obstacle to environmental conservation. Citizens are susceptible to being manipulated by unrealistic images and narratives, aimed at promoting real estate speculation and mass tourism.

It is important to establish an honest relationship between environmental and urban processes for maintaining environmental quality and sustainable development (Minatto, 2015). The landscape's structure and the various ecological elements that compose it are essential for preserving the energy functions and processes in the system. As Minatto (2015) highlights, this interconnectedness means that urban planning must prioritize green spaces, biodiversity, and ecological health to support not only the well-being of the environment but also the quality of life for urban residents. Integrating these elements into urban design can help mitigate issues like pollution, urban heat islands, and habitat loss, fostering a more resilient and sustainable urban environment.

Even if marketed in an astute way by the market, the image of an environment like an estuary, no matter how much marketing it is, is still a product of the system's energy flow. The system's image can be used in different ways and for different audiences. Therefore, the same scenario may be seen in different ways depending on the public. For example, regarding real estate speculation, it is essential to demonstrate a scenario of blue skies and calm seas, which can occur at certain times of the year. On the other hand, the fisherman or navigator searches for a different place, with wind or with plenty of fish. For a bird watcher, what is extremely significant is the presence of birds and the existence of trails. Research discussion on this subject has been conducted in other countries, such as Kahn (2011), who examines the disjunction between fantasy and reality promoted by the tourism industry on the islands of Tahiti. Furthermore, Bolan and Williams (2008) examine the impact of image on the promotion of tourism services and consumer choices, focusing on film-induced tourism in the British Isles.

It is important to acknowledge the importance of direct observation of scientists in their natural environments to identify and refine effective strategies for scientific thinking. It is therefore essential to implement changes to science education based on real-world evidence. Traditional approaches to studying scientific thinking have significant limitations, as laboratory experiments lack real social context, and interviews with scientists can produce unreliable reports. According to Dunbar (2000), traditional approaches to studying scientific thinking have significant limitations. These limitations highlight the need for more direct and comprehensive methods for better understanding and explaining the real world.

The comprehension of the system, based on the energy flow, is more intricate, however, it is closer to reality. It is the responsibility of environmental education specialists to communicate scientific thinking to the public. The Araranguá River estuary, for example, has a sandy barrier and islands near its mouth, as well as a rocky outcrop with a dune field close to the sea. This outcrop is not only decisive in directing the estuary towards the north, but also gives the place an image of rare beauty. The system's image, crafted by the various sectors present there, coupled with the absence of hermeneutics in science, renders it challenging to comprehend what the academy or researcher considers to be authentic.

There are different types of approaches on how to analyze the available information and the narratives that emerge. The term narrative is not common in scientific language. While the term is not typically associated with scientific language, it has gained traction in social science research due to its ability to capture complex social phenomena. Nonetheless, it is utilized in this context to illustrate the hermeneutical concern, in addition to the fact that the rise of the extreme right in several nations, including Brazil, the United States, and Portugal, has garnered the support of a significant number of scholars.

Narratives based on images, provide a framework for analyzing the intricate relationships between individuals, groups, and societal structures, offering insights that traditional quantitative methods may overlook. In order to achieve this objective, it is imperative to establish an engagement movement, such as social mobilization, which serves as a means of social education and biodiversity conservation (Birolo et al., 2022). Social mobilization refers to the process of bringing together community members to address a common cause or achieve a shared goal.

This study demonstrates the significance of the Mãe Luzia and Itoupava rivers as energy sources for the Araranguá River estuary, in addition to the tide and rainfall. This also shows the difficulty of demonstrating the significance of these landscape-forming elements in the management of the Araranguá system. The case of the two rivers, which traverse several municipalities before forming the Araranguá River estuary, necessitates a shared and integrated management at a regional level, which yields tangible benefits for all stakeholders.

V. CONCLUSION

Emergy analysis was successfully used in this work. The analysis enabled the identification of the primary energy sources that maintain the structure of the Araranguá River estuary. Decision-making and the formulation of public policies, such as resource allocation and conservation strategies, can benefit from this.

The sustainability of the estuary is dependent on the maintenance of physical processes, which are responsible for the system's health. The holistic view of the system obtained from emergy analysis is relevant for evaluating the system, including the main actors involved in the environmental management process, suggesting sustainable public policies and minimizing negative effects. It is important to emphasize the importance of communication and education, which can use the information obtained to convey complex processes appropriately to a target audience.

The emergy approach, applied to systems and ecosystem services, reveals the significance of the estuarine ecosystem for the local economic landscape. The contribution value of the Araranguá River estuary ecosystem reveals the ecological potential of the estuary ecosystem, according to a systemic perspective. The importance of the aesthetic function is evidenced by the high emergy value, with 3,3 million emdollars/year.

The results of this study should assist and promote public policies to maintain the ecological and economic potential of the Araranguá River estuary ecosystem, providing a counterpoint to development policies based on real estate speculation. The emergy methodology, as well as the results obtained, show the importance of the technique as a management and decision-making tool. The system's emergy signature clearly and succinctly depicts the primary sources that necessitate attention for the proper care that must be given to the estuary system.

It would make a significant contribution to science to examine energy signatures by comparing various estuaries along the Brazilian coast. In this manner, it would be possible to present unique characteristics in terms of productivity and ecosystem organization, highlighting the importance of the Brazilian coastal zone.

REFERENCES

[1]. Amaral, L. P., Martins, N., & Gouveia, J. B. (2016). A review of emergy theory, its application and latest developments. Renewable and Sustainable Energy Reviews, 54, 882–888. https://doi.org/10.1016/j.rser.2015.10.048

[2]. Barreto, G. A. M. (2011). O papel da maré e da descarga fluvial nacirculação do estuário do Rio Araranguá [Dissertação de Mestrado]. Universidade Federal do Rio Grande do Sul.

[3]. Birolo, A. B., Bacci, E. B., Leão, C. F., & Carvalho Junior, O. de O. (2022). Flag species as a tool in education and social mobilization for biodiversity conservation. IOSR Journal of Research & Method in Education, 12(6), 05–17. https://doi.org/10.9790/7388-1206050517

[4]. Bolan, P., & Williams, L. (2008). The role of image in service promotion: Focusing on the influence of film on consumer choice within tourism. International Journal of Consumer Studies, 32(4), 382–390. https://doi.org/10.1111/j.1470-6431.2008.00672.x

[5]. D'Aquino, C. de A., Pereira Filho, J., &Schettini, C. A. F. (2010). Fluvial modulation of hydrodynamics and salt transport in a highly stratified estuary. Brazilian Journal of Oceanography, 58, 165–175. https://www.scielo.br/j/bjoce/a/CrnJ8j5FKFBvJgCrVW3gswP/?lang=en

[6]. D'Aquino, C. de A., &Peyerl, D. (2022). Social Perception of Renewable Energies in the Coastal Zone of South Brazil. 2022 11th International Conference on Power Science and Engineering (ICPSE), 129–134. https://doi.org/10.1109/ICPSE56329.2022.9935360

[7]. Dunbar, K. (2000). How Scientists Think in the Real World: Implications for Science Education. Journal of Applied Developmental Psychology, 21(1), 49–58. https://doi.org/10.1016/S0193-3973(99)00050-7

[8]. Eryani, I. G. A. P., &Jayantari, M. W. (2019). Water conservation model in Ayung river estuary based on ecotourism. Journal of Physics: Conference Series, 1402(3), 033021. https://doi.org/10.1088/1742-6596/1402/3/033021

[9]. Kang, D. (2013). Emergy-Based Value of the Contributions of the Youngsan River Estuary Ecosystem to the Korean Economy. The Sea: JOURNAL OF THE KOREAN SOCIETY OF OCEANOGRAPHY, 18(1), 13–20. https://doi.org/10.7850/jkso.2013.18.1.13

[10]. Kahn, M. (2011). Illusion and reality in Tahiti's tourist cocoons. Journal of Tourism and Cultural Change, 9(3), 201–216. https://doi.org/10.1080/14766825.2011.620119

[11]. Manique, G. A., D'aquino, C. A., &Schettini, C. A. F. (2011). Transporte de sedimentos em suspensão em um estuárioaltamenteestratificado sob condições de descarga fluvial transiente. Pesquisas em Geociências, 38(3), Artigo 3. https://doi.org/10.22456/1807-9806.35159

[12]. Minatto, C. C. (2015). Morfologia urbana do balneário Morro dos Conventos (Araranguá-SC): Elementos estruturadores e conformação urbana [Tese de Mestrado]. Universidade Federal de Santa Catarina.

[13]. Odum, H. T. (1983). Systems Ecology: An Introduction (1st edition). Wiley.

[14]. Odum, H. T. (1994). Ecological and General Systems: An Introduction to Systems Ecology. University Press of Colorado.

[15]. Odum, H. T. (1996). Environmental Accounting: Emergy and Environmental Decision Making (Edição: 1ª). Wiley.

[16]. Patten, B. C. (2013). Systems Analysis and Simulation in Ecology: Volume II. Elsevier.

[17]. Valle-Levinson, A., Schettini, C. A. F., &Truccolo, E. C. (2019). Subtidal variability of exchange flows produced by river pulses, wind stress and fortnightly tides in a subtropical stratified estuary. Estuarine, Coastal and Shelf Science, 221, 72–82. https://doi.org/10.1016/j.ecss.2019.03.022

[18]. Viera-Romero, A. M., Diemont, S. A. W., Selfa, T. L., &Luzadis, V. A. (2024). The sustainability of shrimp aquaculture: An emergy-based case study in the Gulf of Guayaquil thirty years later. Renewable and Sustainable Energy Reviews, 194, 114326. https://doi.org/10.1016/j.rser.2024.114326

[19]. Voltolini, J., Althoff, D. A., & Back, A. J. (2002). Água de irrigação para cultura do arroz irrigado no sistemapré-germinado. (A cultura do arroz pré-germinado., p. 101–112). Epagri.

[20]. Zhang, C., Su, B., Beckmann, M., & Volk, M. (2024). Emergy-based evaluation of ecosystem services: Progress and perspectives. Renewable and Sustainable Energy Reviews, 192, 114201. https://doi.org/10.1016/j.rser.2023.114201