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Primary Evidenceson the Robustness of Environmental Accounting from Emergy

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Abstract

Agricultural systems operate in the interface between environment and human economy, combining the use of natural and purchased resources in food production. With the aid of the ternary diagram, data of agricultural systems taken from literature are organized in order to evidence the influence of the type of culture and of the analyst's criteria on the results of environmental accounting in emergy. All the systems represented in the ternary diagram determine a qualitatively well-defined region, less or more extended according to the case. Points defined for the emergy coordinates were localized in defined regions observed in the diagram. Emergy accounting is presented as a method able to environmentally characterize production systems in a robust way, even with variations in analyst's criteria and data nature or origin. It is shown that the results of environmental accounting obtained with the use of the emergy methodology are only slightly influenced by the analyst's criteria. On the other hand, the ternary diagram appears as an interesting graphical tool to determine finding and checking robustness of emergy accounting. The robustness of emergy methodology is remarkable.

1 Introduction

Robustness is traditionally investigated during any scientific method development, once the method is at least partially optimized. In this context, the evaluation of robustness during method's development makes sense since the parameters that may affect the method's results can be easily identified when manipulated for selectivity or optimization purposes. Figure 1 illustrates the analogy between parallax error and the experimental design. Two levels are observed: theory and operational. Aspects about the influence of the

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analyst's view point on the construction of the theory model can be found in [1] and[2]. On the operational level, the robustness of experimental design is fundamental for assuring the quality of the experimental observations.

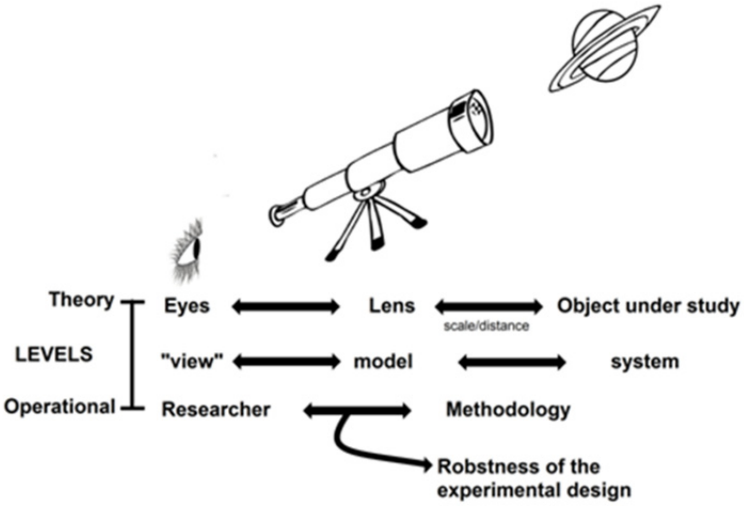

Fig.1 Parallax error analogy in a measurement procedure.

In empirical research, the robustness is a measure of the methodology capacity to remain unaffected by deliberate variations in method parameters, and provides an indication of the methodology's reliability during its normal usage [3]. However, the environmental accounting approaches are quite different when compared to laboratory practices. When performing an environmental accounting, the analyst plays a major role and has strong influence when dealing with the uncertainty arising from incomplete data, limitations of measurement accuracy or available information, extrapolations and interpolations, allocation approaches, and so on. For example, using the Life Cycle Assessment or System of Integrated Environmental and Economic Accounting, the considerations of the analyst can considerably change the results even with the use of available data of proper quality and quantity. In this case, the analyst's influence would be related to the determination of an appropriate aggregating method to combine multiple predictor environmental variables [4].

Currently, environmental accounting based on emergy (spelled with an "m"[5]) is being recognized as an important tool for diagnosis and management of natural and human made systems, under a donor side view and thus being considered as a systemic approach. As with all other environmental accounting tools, the choices of the experimental design depend on the objectives of the analyst. Specifically in environmental accounting based on emergy, authors have being highlighting the influence of several factors to estimate the uncertainty in emergy table calculations. For example, Monte Carlo Simulation [6] and Variance and Taylor methods [7] were used to assess uncertainties associated to the use of Unit Emergy Values (UEV) and the raw data inputs in the inventory table. In both works authors were interested in evaluating error propagation and/or result's sensitivity related to uncertainties embodied in raw data feeding emergy accounting tables. These studies have shown powerful tools aiming to check robustness of emergy methodology; however, Goupy[3] argues that it is necessary to differentiate checking and finding robustness, which should be considered separately.

The procedure to study the robustness of the method is called finding robustness, meaning the discovery of an experimental condition in which the measure capacity remains unaffected by deliberate variations in procedural parameters. Regarding specifically environmental accounting methods, finding robustness means that results would not be influenced by the changes of accounting factors under control of the analyst's criteria. Once the method´s robustness is consolidated (or found), checking robustness aims to verify the reproducibility of the method. The verification may enable to assess the method´s response to variations among different studies. It is recommended that checking robustness should be made only after robustness of the method is obtained.

Among the existing ways to assess the robustness, the ternary diagram [8,9] is able to graphically reveal the experimental region where inaccuracies introduced by the analyst have considerable influence on results. Considering that uncertainty is a measure of the results' reproducibility and reflects the robustness of the methodology, the ternary diagram could help in assessing the method's robustness when different results are compared - either if obtained by the same analyst or by several distinct ones. By using ternary diagrams tographically represent emergy indexes of several case studies, Almeida et al. [9] and Giannetti et al. [10] have identified different regions of domain according to the nature of the systems under investigation (i.e., agricultural, industrial, cities, countries, etc.) and management (i.e. organic and conventional agricultural production, electricity production based on fossil fuel, etc.), leading to an idea that ternary emergy diagrams could also be used to assess the method's robustness of environmental accounting based on emergy.

Regarding agricultural production systems, it is recognized that they operate on the interface between environment and human economy systems, thus combining the multiple contributions of natural and purchased resources resulting in an extended inventory. Agricultural systems have being evaluated under emergy accounting tool and their results represented by using the emergy ternary diagram ([11-14] among several others). Since region domains were recognized in the diagram according to the nature of the analyzed systems [9,10], it is expected to find a specific region (area) characteristic of agricultural systems within the diagram. In the same way, variations on the emergy flows (renewable, non-renewable and feedback from economy) are also expected as a consequence of different raw data and/or analyst's considerations, even when the study focuses on the same kind of crop. This work explores the influence of agricultural systems type (i.e., crop's type, management, geographical region, etc) and the considerations taken into account by the analyst on the delimitation of regional domains within ternary diagram. The results are compared and discussed under the goal of finding and checking robustness of environmental accounting based on emergy.

2 Methodology

2.1 Emergy accounting

Emergy accounting methodology [5] was developed as a tool for environmental policy and to evaluate the quality of resources in the dynamics of complex systems. Briefly, emergy is defined as the sum of all inputs of energy directly or indirectly required by a process to provide a given product or service – its units are in solar energy Joules (seJ). Further definitions and rules regarding emergy accounting can be found in [5] and [16].

The emergy flows represent three main categories of energy sources (Figure 2): natural renewable resources (R), non-renewable natural resources (N) and those ones feedback from the economy (F). All the three categories are fundamental in emergy accounting and enable the understanding of system interactions with the environment. The R and N flows are provided by the environment and are considered as free-of-charge under the economic viewpoint. While the renewable resources can be replaced at least at the same rate as they are consumed, the non-renewable resources are depleted faster than their natural ability of recovering. The economic inputs (F) are provided by the market. The output (emergy yield, Y) is the sum of all emergy system inputs.

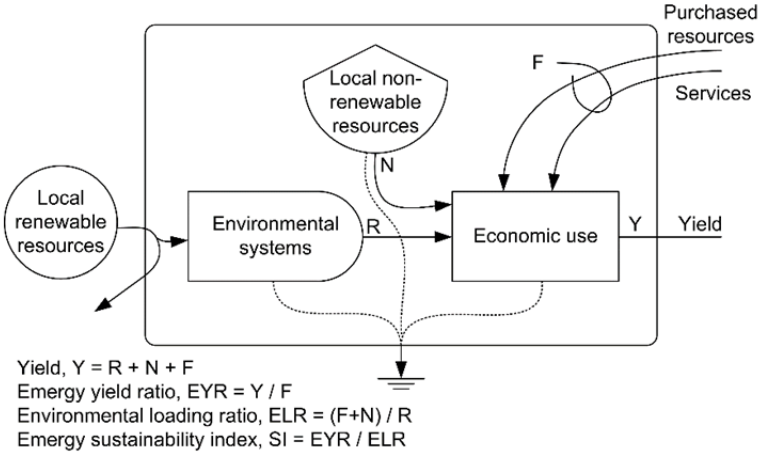

Fig.2 Description of emergy fluxes and indices.Adapted from [17].

2.2 Ternary diagram

The ternary diagram based on emergy[8,9]was proposed as a graphical tool to assist emergy evaluations. The graphical representation of the emergy data makes possible a comparison among processes and systems, the proposition of improvements under scenario studies, and a dynamic study over time. In short, this graphical tool allows a quick and efficient interpretation of results, supplying important information to researchers and decision makers.

The graphic tool produces a triangular plot of three variables (R, N and F) with constant sum. These fluxes are represented by an equilateral triangle, in which each corner represents a flux and each side a binary system. Points within the triangle represent ternary combinations. The relative proportions of the three elements (R, N and F) are represented by the lengths of the perpendicular lines from the given point (system graphed) to the side of the triangle opposite to the considered element (Figure 3). Hence, the characteristic of any point plotted within the ternary diagram is determined by reading from zero along the basal line at the bottom of the diagram to 100% at the vertex of the triangle.

Among the several assessment approaches allowed by using the ternary diagram, only the resource flow lines (Figure 3) and the equi-values lines (Figure 4) are presented here. The lines related to equi-values of environmental indices allow an immediate verification of the emergy indices EYR, ELR, EIR and SI as every point that lies along the line presents the same value.

2.3 Checking the robustness of environmental accounting in emergy

Considering this short communication as a preliminary expression of authors' initial thoughts, only selected published results about emergy evaluation of agricultural systems are used as case studies. Data of agricultural systems taken from literature are organized in order to evidence the influence of culture type and analyst criteria on the system emergy performance and their representation by using ternary diagram graphic tool. The robustness approach adopted here consists basically in determining how initial choices for some accounting variables and procedures can influence on emergy methodology performance.

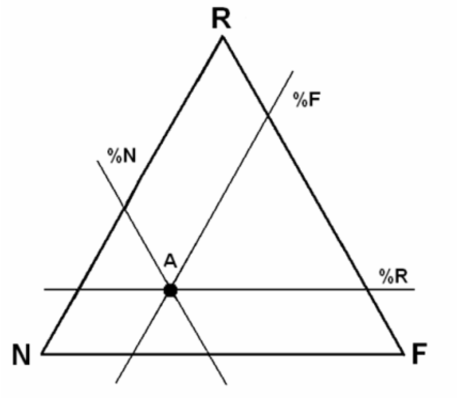

Fig.3 Representation of a general system ("A") with the relative proportions of R, N and F fluxes. The sum of R, N and F represents 100%, i.e. total emergy.

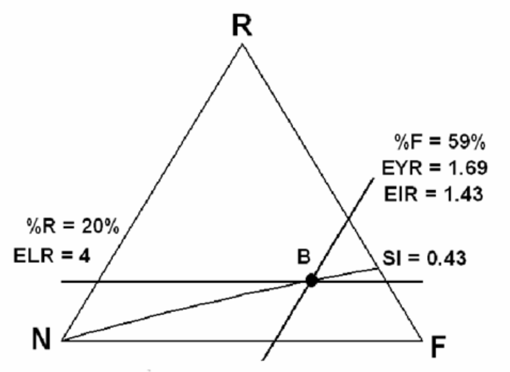

Fig.4 Representation of a general system ("B") with the lines related to equi-values for the sustainabil-ity index.

3 Results and discussion

Data about a selected group of agricultural systems assessed under emergy accounting were taken from literature in order to establish comparisons among their performance (i.e. the behavior of related point's position) within the ternary diagram. Data analysis were organized as follows: (i) considering data from the same cropped species but quantified by different authors or subjected to different considerations among them; (ii) data from different cultures but quantified by the same authors or under the same conditions; and (iii) data related to the same culture and presented by the same authors.

3.1 Assessments of the same agricultural products

3.1.1 Corn crop

Data regarding corn crop agricultural production were taken from [15,18-22]. Even producing the same output, data corresponding to corn crop are characterized by divergences in management (maybe due to local characteristics, geography, technology adopted, etc.) among the cultures. To foresee the influence of the amplitude of these variations on the results is not easy, so the complete data set were firstly plotted in a ternary diagram (Figure 5). The organic corn emergy performance [22], *a priori* recognized as a different agricultural management, was included in the analysis to act as a "reference" to qualitatively investigate the effect of including a different consideration in a same group to be evaluated. Thus, the ability of the ternary diagram in evidencing intrinsic differences for the same species culture was also tested.

Figure 4 shows that lines of equi-values indices limit a region of domain (in gray color) for the majority of the systems under study (points 1, 4, 5, 6 and 7). The points 2 and 3 lay far from the other ones, and were initially unconsidered to establish the domain region due to reasons discussed below. Point number 2 corresponds to the organic corn crop production [22] and probably differences in the system´s management or origin of the crop could explain the considerable distance from the more concentrated region. Organic production is recognized as low dependence on external resources from economy (mainly fertilizers), reducing its demand for resources “F”. Point number 3 corresponds to conventional corn crop produced in Kansas, USA [21], and it is characterized by a high proportion of purchased inputs when compared to the systems located within the domain region in Figure 5. Very likely, this happened because Martin and coworkers accounted for irrigation water as an “F” resource, which represents 49% of system’s total emergy demand. All other points are grouped in a domain region. Work related to points 1, 4, 6 and 7 do not include irrigation water in the conventional corn crop production, contrarily to point 5 that accounted for this resource.

An “if scenario” analysis was performed in order to evaluate the influence of analysts’ criteria in assigning for an emergy resource category instead other one. The irrigation water input for point 3 was originally considered as 100% seJ/seJ from “F” source, on the other hand, for system represented by point 5 is considered as 50% from “R” and 50 % from “F” sources. If the same considerations established for point 5 were applied to point 3, the generation of a new point (namely 3’) was observed in Figure 5. This scenario results in an improvement of EmergySustainability Index (SI) for point 3 from 0.05 to 0.2. For a second “if scenario”, in which the irrigation water is now considered as 100% seJ/seJ coming from “R” source, the point 3’’ is generated showing a SI index of 2.1.

3.1.2 Sugarcane

Data regarding sugarcane agricultural production were taken from [23] and [20], both represented in Figure 6. Four points were considered and the domain region have initially excluded one of them (point 1). While the system represented by point 1 have a high value for topsoil loss (representing 63% of system’s total emergy demand), point 4 accounts for about ten times lesser the erosion soil rate than point 1. This explains the distance between points 1 and 4.

An “if scenario” was applied to point 1 in order to evaluate the influence of an unexpected decrease in its original topsoil loss rate. If the value of topsoil loss of point 4 was considered for point 1, point 1’ will be generated and the decrease in “N” resources inputs results now in a movement of the original point 1 to point 1’, within the domain region.

For the system represented by point 1, the irrigation water is considered as 50% coming from “R” sources and 50% from “F”. If the analyst criterion was modified, in which the irrigation water was considered as 100% “F”, point 1’’ is generated from 1’.

3.2 The assessments ofdifferent agricultural products

To evidence the influence of different agricultural production systems on the domain region defined in the diagram, data published by [20] were considered as case study. Considering that all these data were handled by the same authors, differences concerning the criteria among data should be, at first, not present. Points related to emergy systems performance were placed within the ternary diagram in Figure 7.

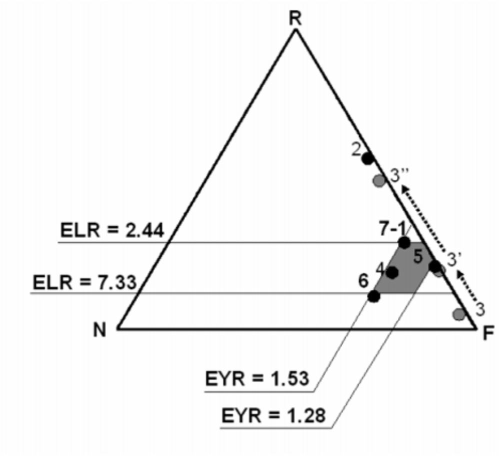

Fig.5 Ternary diagram representing the emergy performance of different corn crop production systems: (1) Chianti, [19]; (2) organic management in Italy, [22]; (3) conventional management in Kansas, [21]); (4) USA, [20]; (5) Italy, [15]; (6) Florida, [20]; (7) Tuscany, [18]. Points 3' and 3'' were generated from point 3 through calculations cited in the text.

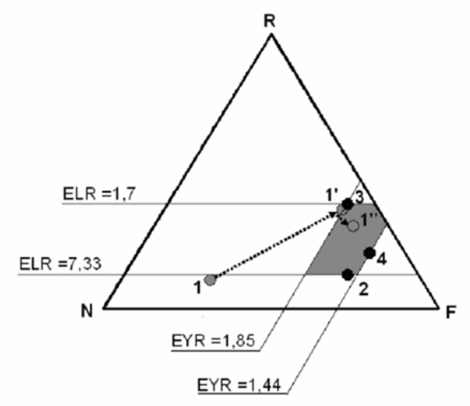

Fig.6 Ternary diagram representing the emergy performance of sugarcane plantation systems: (1) Florida (Everglades), [23]; (2) Brazil, [23]); (3) Louisiana, [20]; (4) Florida, [20]. Points 1' and 1'' were generated from point 1 through calculations explained in the text.

The region depicted in Fig.7 is more extended than those representing a unique crop system (Figures 5 and 6). The intrinsic characteristics of each culture are evidenced since criteria used for handling data are normalized. The limits of the region correspond to tomato (point 2) and soybean (point 4) cultures. Tomato case accounted for high amount of labor and services due to the culture requirements. These inputs represent 30% of the total system's emergy demand, and they were assumed as 96% from "F" and 4% from "R". Oppositely, the soybean systems have services contributing on 10% of total emergy, and it was assigned as 40% from "R" and 60% from "F".

Differences due to system nature (i.e., even they are all agricultural products, they have different energy requirements to grow) and in this case, also to differences in input category assignment, resulted in a wide interval of SI values, ranging from 0.05 (tomatoes case) to 1.1 (soybeans case).

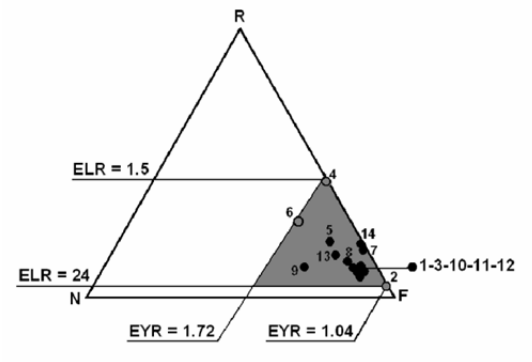

Fig.7 Ternary diagram representing the emergy performance of various agricultural systems production published by [20]: potatoes (1), tomatoes (2), watermelon (3), soybeans (4), sugarcane (5), oats (6), oranges (7), cabbage (8), sweet corn (9), cucumber (10), green beans (11), lettuce (12), peanuts (13), and pecans (14).

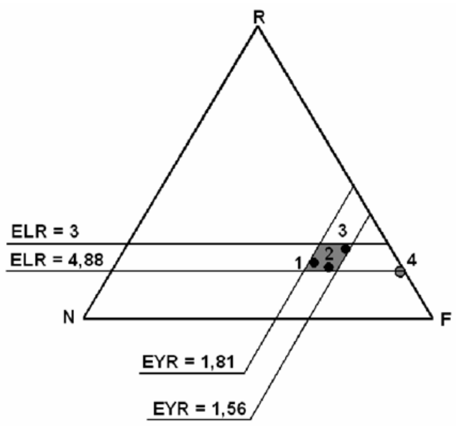

Fig.8 Ternary diagram representing the emergyperfdormance of vineyard cultures: (1) Chianti case; (2) Brunello di Montalcino; (3) Nobile di Montelpulciano; (4) Italian average. Data from [19].

3.3The assessments of the same culture

Three high quality vineyard cases [19] were chosen to avoid divergences due to differences in analysts' criteria and to the influence of the culture´s nature. All the vineyard culture data come from the same Italian region, so divergences arising from climate or geography are inexistent. Preliminary results shows that, considering the same agricultural production and region, and the same analyst applying emergy evaluation, the domain region (Figure 8) comprising the points is the smallest among all those previously observed.

It should be noted that the point obtained from Italian vineyard average (point 4) is located out of domain region. This characteristic was expected, as point 4 represents all kinds of management and all kinds of vineyards in the country. The ternary diagram seems to be a useful tool to evidence any type of divergences among data. Divergences may arise from differences in the year production, but probably this is not the main driver since there are other important differences involved. Data related to Italian vineyard were extracted from calculations taking into account average values for raw data (for example rainfall, topsoil loss, labor demand, etc.) and neither represent any specific type of vineyard, quality of vineyard, geographical area nor reflect any specific climate condition, but a tendency of the whole Italy. Oppositely, Tuscany vineyard represents a local situation and any comparison with the Italian vineyard culture has to be carefully made.

4. Final commentaries and implications

Two main findings can be drawn from the previously discussion. Firstly, all the agricultural systems considered as case study determine a defined domain region, less or more extended according to the case and despite of differences in the analyzed variables. The more distant points correspond to well-specified cases, for instance, those ones adopting organic management and/or land with high tendency to topsoil erosion.

The second finding is related to emergy methodology and the use of the ternary diagram. Even considering this study a preliminary approach needing further deeper assessment, results indicate emergy accounting as a self-consistent method, i.e. with high robustness. Further assessment of such robustness can be achieved by applying the ternary diagram method to data representing other production systems and analyst’s criteria. Emergy shows to be a method able to characterize production systems in a robust way, even considering variations in analysts’ criteria or system nature. The robustness of emergy methodology is remarkable, especially, when one considers it in comparison with others accounting methodologies[24-26].

The differences found on the few case studies considered do not indicates that the authors made an incorrect analysis, but instead that pointed out the need for normalizing criteria related to emergy accounting, in order to avoid subjective or non-sustained analysts' decisions that could hinder analysis reproduction or comparison. In this sense, the efforts of the International Society for the Advancement of Emergy Research (ISAER; www.isaer.org) starting the discussion and organizing work groups to make recommendations for standards in emergy is strongly welcome.

Further studies on finding and checking robustness are in development to deepen discussion and verify the emergy methodology.

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