REVIEW PAPER

Methodologies for evaluating farming systems. Part II: Energy efficiency (EMERGY), farms' trajectory and an example of a whole farm model (GAMEDE)

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ABSTRACT: This paper is the continuation of the one published in Pastos y Forrajes, no. 1, 2016, in which the general bases of a selection of currently internationally available methodologies for the dynamic evaluation of production systems, are offered. This part describes the methodologies Integral Energy Evaluation (EMERGY) and Systems' Trajectory; and also a concrete example is provided of the application of the principles of these methods in the construction of an integral evaluation model of farming systems, called GAMEDE.

Keywords: animal production, evaluation, quality of energy

Integral Energy Efficiency (Emergy)

Emergy is the methodology that refers to the total quantity of useful energy of a certain type, which has been directly or indirectly used in the necessary transformations to generate a product or service (Odum, 1996). For such purpose, the quality of the different forms of energy from such resources as sunlight, water, fossil or mineral fuels, work, etc., is taken into consideration, and in fact measured (fig. 1). The measure unit is the emjoule (emJ); which refers to the useful energy of type 'X', which is consumed in the transformations that occur in the natural, ecological or human systems, and which has a certain capacity to perform work. The recognition of those «quality» differences is a key concept in this methodology, which allows the evaluation of the use of all the resources consumed in a given system, with different possible analysis boundaries, through the quantification of the diverse energy sources that participate in a process and the counting of the input, circulating and output flows of each unitary source. This method seems to have advantages with regards to others that also analyze the energy efficiency at different levels, such as, for example, the Energy Analysis or the Ecological Footprint (Vigne *et al*., 2012).

Such method responds to the first mention of the energy hierarchy principle and states that «the quality of energy is measured through the energy used in transformations» from a type of energy to the next. These energy quality factors have also been represented in terms of fossil fuels, and have been called Fossil Fuel Work Equivalents (FFWE), whose approximate equivalence is of one kilocalorie of fossil fuel or around 2 000 kcal of sunlight.

The theoretical and conceptual bases of the emergy methodology are found in thermodynamics, the general system theory (Von Bertalanffy, 1968) and the system ecology (Odum, 1983). To understand the history of this theory, two publications should be consulted: *Maximum Power* (Odum, 1995) and *Environmental Accounting* (Odum, 1996).

Vigne *et al*. (2013) applied Emergy to compare the energy efficiency of cattle milk production systems,

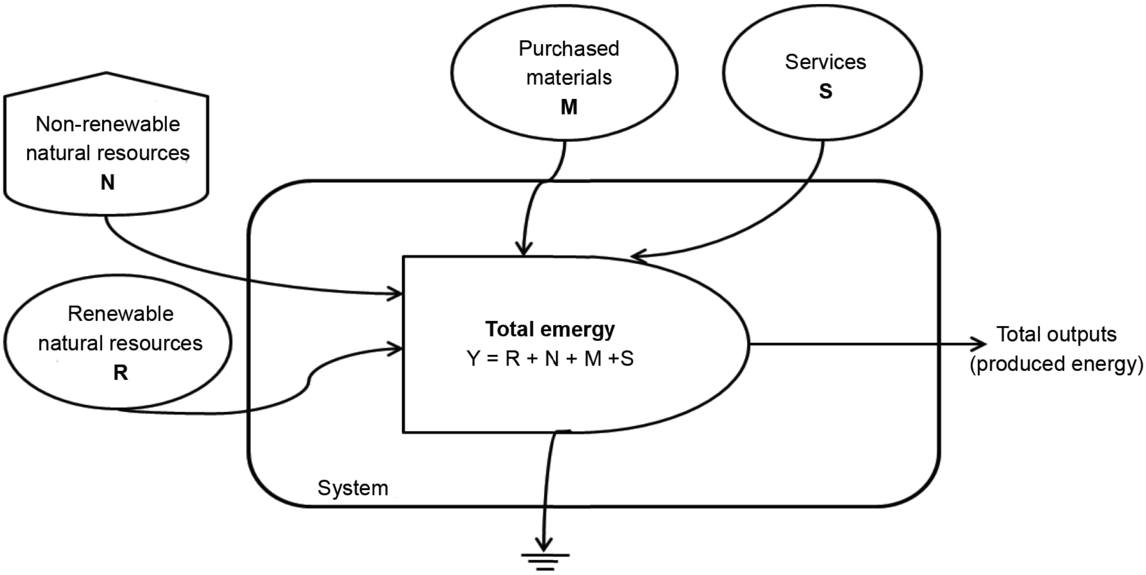

Figure 1. Diagrammatic representation of the energy types comprised in the analysis of a system, using the Emergy methodology (adapted from Vigne et al., 2013).

under contrasting socioeconomic and edaphoclimatic conditions. The starting point was considering the set of energies present in the system, to calculate their conversion efficiency in the implied processes of interest (for example: biological, production processes, etc.). The evaluated systems were: a) low-input system in southern Mali (Africa), b) and c) systems with moderate utilization or little dependence on external inputs in two regions of France (Poitou-Charentes and Brittany), and d) high-input system in Reunion Island. The results of this study showed that the system in Mali used the lowest total quantity of emergy at all levels, and it was the one with the highest utilization of renewable resources and energy. The study allowed to identify remarkable differences in the transformation efficiency of the available resources and the respective impacts on the environment.

On the other hand, Martin *et al.* (2006) analyzed three agricultural systems from the United States and Mexico, in order to compare the utilization of resources, productivity, impact on the environment and global sustainability. These authors acknowledged the usefulness of Emergy to transform the different types of energy into a common form (solar energy equivalents) and allow the useful comparisons among diverse and contrastable systems.

Similarly, the use of this methodology allowed to question public policies and strategies in China, which were aimed at substituting the rice production at national level by vegetable production (Lu *et al.*, 2010). It was proven that this decision would be justified, only, by economic reasons (capital inputs/outputs) and at short term; but never by reasons with an integrated (environmental, renewable energy use and economic) approach and with long-term strategies.

Likewise, Rótolo *et al.* (2007) used the Emergy approach to evaluate the cattle grazing system in the Argentinean Pampa, globally, in its environmental and economic context. The study showed that rainfall contributed with 61 % of the total emergy of the grazing system. The natural pastures showed 85 % of dependence on renewable resources, and less than 4 % with regards to the imported inputs in the system. On the contrary, the planted pasture and the corn depended on 41 and 35 %, respectively, of the externally acquired (purchased) resources. In general, it was observed that the grazing system in this region is sustainable from the environmental point of view, with low impact on the environment. Nevertheless, with this analysis it was proven that in the core of the global system there are subsystems in which cattle grazing depends, to a large extent and with regards to certain stages of its cycle, on external inputs, as well as on non-renewable resources, but in a moderate way. Natural pastures showed the best environmental sustainability, mainly due to the scarce losses of organic matter from the soil.

Systems' trajectory. Why analyzing it?

The analysis of systems' trajectory is justified by considering three key elements of the system approach (Le Moigne, 1990). Firstly, the fact that systems are transformed in time. Analyzing a farming system means, above all, studying its function in a given instant *t*, or along an annual cycle, such as, for example, through the use of methodologies like the Ecological Network Analysis (ENA) or Emergy, which can examine the behavior of the flows accumulated during a period. Secondly, the transformations of the system structure and the evolution of its purposes, goals or long-term objectives (for example, in a period of several years), should be evaluated.

On the other hand, an agricultural system should be considered as an open system, capable of making changes as response or anticipation to the evolution of its environment (climate, market, etc.) or to disturbances that affect the farms of a region or territory at a given moment. The changes can also be considered responses to events occurred within the system (for example: evolution of the family and the labor), which in turn affect the farms at different moments of their life cycle. From these analysis elements, pertinent issues arise, such as the perenniality of the systems or their capacity to last and maintain their structure and purpose, amidst an uncertain and constantly evolving environment.

In addition, agricultural systems are managed by individuals or communities, which implies stating the hypotheses: i) of limited rationality, that is, farmers have their reasons to do what they do, and ii) of adaptive behavior (Brossier *et al*., 1997), that is, farmers make decisions depending on the information they have (which can be incomplete), and on the purposes they assign to their systems, amidst a series of limiting factors. This rationality can emerge from an economic perspective: farmers choose the activities and ways of producing, according to their interests and their means. Their decisions can also respond to another series of cultural or social factors, mainly. The above-stated facts refer to the issue of the sense given by farmers to their action, according to their own points of view (Darré, 1996).

Thus, the trajectory analysis of agricultural farms allows to evaluate the changes and transformations performed by their main actors, amidst an often uncertain and constantly evolving environment. This study is comprehensive, because it is about: i) understanding the reasons that cause change (or resistance to change), ii) characterizing the sense given by farmers to their behaviors, iii) identifying the conditions under which farmers adopt other production ways, and iv) understanding how farmers act in an uncertain situation.

The objective of such comprehensive approach is to propose new evolutions, in coherence with the farmers' situation; in this sense, the works carried out by Napoléone and Chia (2010), related to the coordination among actors around the seasonal variation of goat milk production in a certain region; or the works conducted by Ryschawy *et al*. (2013), about the strategies to maintain agriculture-livestock production systems in a territory. This approach also intends to motivate the reflection of the actors of the productive chain on their actions or decision-making, so that they modify their representations of the situation and its dynamics (Pluvinage and Moulin, 2007), or even evaluate the sensitivity or soundness of their systems (Nascimento de Olivera, 2014).

What methods should be used to analyze the systems' trajectory?

According to Teno *et al*. (2013) there are four large groups of methods to evaluate the systems' trajectory. The first one is composed by the monitoring of the farms, which is organized by research institutions (for example: INRA in France; Benoit and Laignel, 2011); the monitoring of technical support (for instance: the Limousin Cattle Breeders Network –Réseau d'elevage bovin Limousine–, 2012); and the monitoring of development, such as the Enterprise for Textile Development of Mali –Compagnie Malienne pour le Développement du Textile– (Sanogo *et al*., 2010). Such monitoring allows an annual record of databases, structures and socioeconomic results. This method is reliable, because it allows the collection of numerous quantitative data. However, as it focuses on the analysis of the changes that are occurring and their impacts, it requires many years (5-10 as minimum) before being ready to analyze the trajectory made by the system in question. In addition, this methodological approach needs important means to put farm monitoring into practice: the samples that are selected should be in a range of around 20-30 farms, with much collected data (monitoring with research objectives), or up to 200-300 farms, with a more restricted data volume (of the monitoring-evaluation type, in the

framework of the objectives of local development or support structures, technical advisory).

The second method is based on the planning of instantaneous surveys to a relatively large sample (50-200 farms), which facilitate the characterization of the diversity of farms in a certain instant *t*. The surveys are applied from five to ten times in the same samples, in order to have a new status of the farms at a moment *t* + 1. The comparison between *t* and *t* + 1 allows to reconstruct the trajectory of the farms between two certain dates (García-Martínez *et al*., 2009; Dai, 2010; Ulrich *et al*., 2012).

For example, to analyze the factors of pastureland degradation in two communities of eastern Amazonia, Navegantes-Alves *et al*. (2012a) used data from surveys made in 2003 and repeated in the same farmers (n = 53) in 2008. This allowed to identify stable trajectories, because the systems showed little evolution in their structures and their functioning; as well as farms that had followed evolution trajectories towards other system modalities (for example: cattle-specialized or diversified systems), that is, fluctuating trajectories, without a well-defined orientation (table 1).

The analysis of the pastureland management and the vegetation status showed that, with the same management regime (for example: continuous grazing or slow rotation), the invasion of weeds was lower in the case of farms with stable trajectories; the stability of the medium-term management practices, seemingly, was a favorable factor from the point of view of the vegetation balance. This method equally observes the changes that occur in a given period, which requires to wait several years before being able to analyze the medium-term technologies. Based on the surveys during more spaced time intervals, this methodology allows to work with large samples, for which it can be extended up to several hundreds of farms.

The other two methods are based on the application of retrospective surveys, which allow to re-constitute the history of the farms, through a call to the memory of the farmers and actors closer to the farm. Both are differentiated by the type of data collected. The first proceeds so that the status of the farms is explained at regular time intervals (for example: every five years), based on a list of quantitative (area, herd, etc.) or qualitative criteria (presence of extra-agricultural acivities, social type of the family, etc.). With the use of this method, Rueff *et al*. (2012) described the evolution of eleven variables, since 1950 until 2003, for the case of 24 farms of five municipalities of the Pyrenees in France. The statistical analyses used in this and other examples, and emerged from disciplines such as ecology (Dolédec and Chessel, 1987), allowed to characterize the evolution *a posteriori* and construct trajectory typologies.

In the case of the second method, making retrospective surveys is the basis that allows to identify the events occurred since the beginning (Moulin *et al*., 2008). From the knowledge of the history of the farm, through a good location in time of each of the events and changes occurred, the connection points among them are established (a change in a certain date causes another later change) or to the events or evolutions occurred in the environment of the farm.

Table 1. Farms' trajectory in two communities of Eastern Amazonia between 2003 and 2008, after a colonization process between 1985 and 2000.

		Stabilized Trajectory		Variable Trajectory		
		Specialized	Diversified	Towards specialization	Towards diversification	Fluctuating
Number		21	5	14	4	9
Herd size (head)	2008	46	62	34	19	31
	2003	51	76	43	8	15
Pasture surface (ha)	2008	39	74	17	18	33
	2003	41	78	41	21	22
Forest area (%)	2008	13	15	45	20	16
	2003	10	14	20	17	16

Source: Navegantes-Alves *et al*. (2012a).

Likewise, the analysis of the farm history allows to differentiate periods, through which coherences are identified among the structure, the functioning and the objectives of the family, by means of which gradual changes could have occurred, without questioning such coherence (fig. 2). Among those periods deep transformations that affect the system can be detected, allowing to go from the analysis of one coherence to another, in a more or less long period of time (from 1 to 3-4 years. Thus, the analysis of a set of trajectories of livestock production farms allows to construct typologies of trajectories or make transversal analyses in a specific topic.

Taking such method into consideration, Morin *et al*. (2007) identified three types of trajectories of cattle production, which guaranteed the local milk demand in the market of Ségou city (Mali). On the other hand, Moulin *et al*. (2004) studied the factors that influenced the elimination of the tensions that were produced, for example, when the stocking rate was not increased and the herd size was increased.

The two above-described methods can be frequently articulated, which facilitates the complementation of the approach per statuses with the performance of complementary interviews, which make emphasis on events detected in the analysis of the stage changes (Ryschawy *et al*., 2013). The approach per event would allow the *a posteriori* reconstruction of the status evaluations at regular time intervals (Morin *et al*., 2007). These retrospective methods (developed in France) have been used in many contexts, in France (Madelrieux *et al*., 2015) as well as in other countries (Coulibaly *et al*., 2007; Navegantes-Alves *et al*., 2012b). However, they show two main difficulties. Above all, the fact that they are based on the farmers' memory, with all the justifications and judgments this involves, which demands *a posteriori* rationalization in the exercise of interpreting the results, depending on the changes occurred. On the other hand, the surveys are performable only in farms that still exist. Although it is true that the investigation of the factors that determine the perenniality of these farms is possible, these methods do not allow to work or study about the factors and conditions which have determined the disappearance of other farms. Nevertheless, the great advantage of these methods is that they allow to research the trajectory, from the surveys conducted in the field, in a reasonable time period (for example: a few months).

Integral system evaluation: the example of the GAMEDE model

In order to explain the practical validity of ecological intensification as a way to harmonize the objectives of local development, food security and environment protection, in a context of exponential growth of the world population and thus, of food demand, Vayssières *et al*. (2011) applied integrated

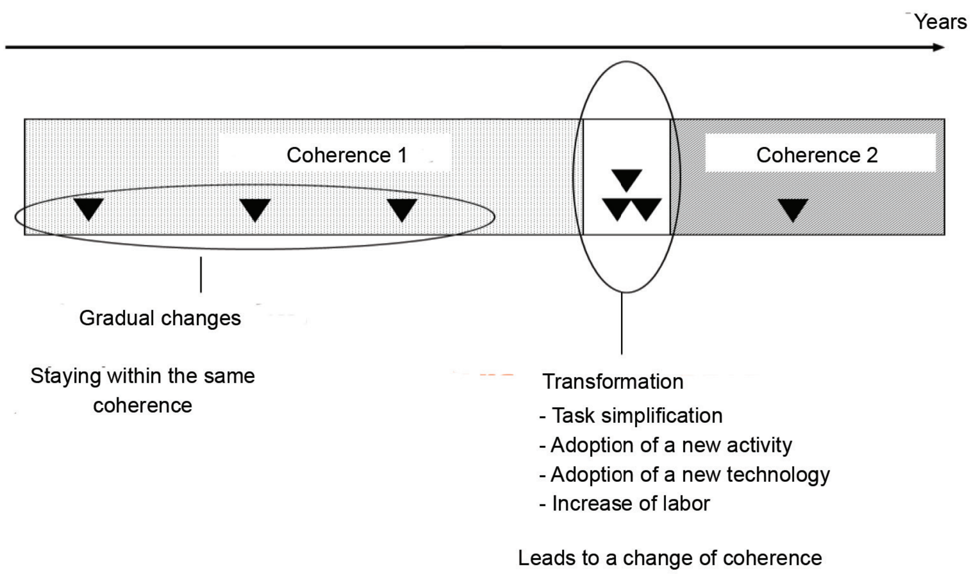

Figure 2. Graphic representation of a system coherence and transformation period from the analysis per trajectory (Moulin *et al*., 2008).

participatory modeling techniques to accompany local decision-making policies. These authors, with a systemic approach, dealt with concepts at different levels and made emphasis on the farm scale. For such purpose they used the GAMEDE tool, which is an integrated analysis model of the farm, conceived and developed with these aims (Vayssières *et al*., 2009a, 2009b).

Such model is an example of the application of the principles and concepts that are approached in this paper for the specific conditions of a territory or locality (in this case, Reunion Island). The context variables, in detail; the dynamics of the main biophysical and decision-making processes which affect the use of labor; the margins of economic profit; as well as the nutrient and energy flows at the level of a series of farm typologies, are taken into consideration.

The analyses with the use of GAMEDE intend to further study the possibilities of optimizing the ecological and natural processes, to improve the efficiency of production; for example, through the promotion of integrated agriculture-livestock production systems and the companionship of policies that catalyze their development, by means of a better understanding of the implicit dynamics.

The fact that these models integrate the set of implicit compartments in the system, at different levels, allows to couple different methodologies. Thus, without stopping the use of GAMEDE, for example, further studies could be conducted on the efficiency of energy utilization with the Emergy methodology, or ENA if it is about the nutrient flows (Álvarez *et al*., 2014), or the studied systems' trajectory could be taken into consideration.

CONCLUSIONS

The methodological tools approached in this paper undoubtedly contribute to the development of an immense range of methods interested in the research of the dynamics of farming systems. Their implementation allows great flexibility to respond to two of the most important challenges faced by researchers at present: 1) the need to put into practice a multidimensional evaluation of farming systems (the dimensions refer to the organization levels –from family to society, in a country or at global scale–, but also to the economic, social and environmental dimensions that affect the system functioning). The combination of these tools offers a variety of perspectives about the systems, which contributes to identify synergies and antagonisms among such dimensions; 2) the identification of the key determinants for the conception and diffusion of the most interesting systems to face the global changes and challenges of present times (demographic growth, erosion, desertification, climate change, etc.). The research for the conception of new systems and their diffusion can be supported by the use of these tools to understand the current and future socioeconomic functioning logics and design new systems with the participation of all the actors implied in the chain.

Such flexibility in the possibilities to use these methodological tools is translated into the availability of an immense range of methods, which increases the rigor and richness of the analyses of complex systems, independently from the proposed objectives and from the edaphoclimatic and socioeconomic conditions in question.

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