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Emergy Evaluation: A Tool for the Assessment of Sustainability in Project Development

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ABSTRACT
This contributiondescribes the basic principles of the emergy accounting method as a technique for quantitativeassessment of sustainability in developing projects. Emergy determines the amount of energy used directly and indirectly for generating resources, services and products. In addition,this analytical method integrates economics, ecology and thermodynamics.This allows a comprehensive assessment of the economic, social and environmental impacts in a theoretical way. Currently, Emergy evaluation is considered as one of the life cycle sustainability assessment methods in areas similar to ecological, economics, and environmental engineering.
Furthermore, the entire methodological path for the application and development of the emergy accounting method was well described. In addition, some case studies where emergy has been the key data needed for sustainability decision making were analyzed and discussed. This work further provides the practical connection between theoretical definitions of emergy, data needs, and mathematical definitions of indicators for emergy sustainability assessment. With the accomplishment of this contribution, emergy assessment can be achieved and proposed as a tool for the development of sustainable projects.
Keywords–Ecology, Economics, Emergy, Energy Sustainable development.

I. METHOD OF EMERGY ACCOUNTING

To talk about emergy, two concepts have to be clarified: *energy quality* and *transformity.*

1.1. Energy quality and transformity.

H.T. Odum observed that all the auto-organization systems (e.g. ecosystems) are ruled by the first and second laws of thermodynamics.The amount of valuable energy decreases when passing from an inferior to a superior level of the auto-organization. This is because there is no one hundred percent efficiency in the process of transformation. But, the energy that is necessary for the construction of higher levels is greater as the system becomes more complex [1]. In this way, energy concentrates as it moves towards each of the auto-organization levels as is shown in **figure 1.**

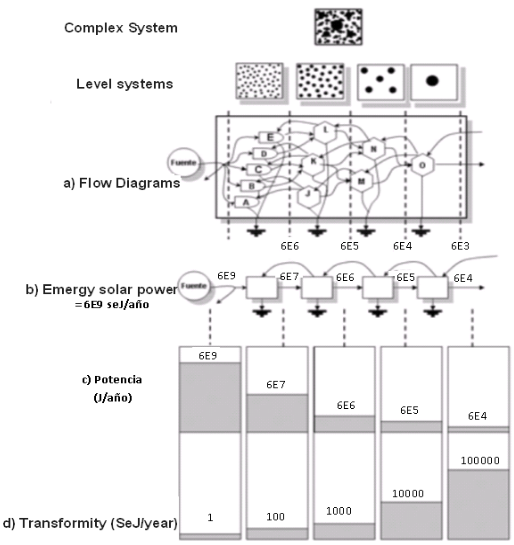


Figure 1. Energetic diagram of the hierarchy in the energy transformation. Source

Taken from Rydberg & Haden, 2006 Emergy evaluations of Denmark and Danish agriculture: Assessing the influence of changingresourceavailability on the organization of agriculture and society. (Complex system – Level

System – a) Flow diagram – b) Solar emergy potency = 6E9.

Therefore, this observation implies that 1 joule of solar energy, 1 joule of coal or 1 joule of electricity, although they represent the same ***quantity*** of calorific energy (1 joule), they do not share the same ***quality*** in terms of the potential that these different types of energetic sources have to act on the system. That is, the need of receiving higher of lower quantities of less concentrated energy for generating each of them". [2].

Figure 1 indicates that there is a decrease in energy in each transformation of the process. At the same time, more energy is required (transformity) to produce elements that are on the right side of the figure (higher level of the chain).Therefore, these products (which are further from the chain) have a better quality, scarcer, and greater value.

Then, there exists a hierarchy of energies according to their quality o potential to influence the system. This goes from low concentration energy sources (e.g., the sun) to highly concentrated ones (e.g., petroleum) [3,4].

It is supposed that solar energy is the main and primary source of low concentration energy entering to the ecosphere. The most abundant source of energy in the earth is solar light.But, due to the fact that it flows in time and space, it has a low quality compared to other similar energy sources derived from it.Therefore, solar energy is chosen as the energy of reference in emergy analysis.Transformity would have units of seJ/unit of energy (solar equivalent joules/unit of energy).

By this way, transformity increases to the right and it is a measure of the quality of energy. Since available energy has had to be degraded (its availability has been utilized) in each transformation, as more transformations are required to generate high quality elements on the right, less energy will be left.Thus, an entry to the process with a high transformity contributes with less energy to the processthan one with a low transformity entry [2].

Transformity values represent a general principle: "high quality products should not be used for low quality purposes" [3]. For instance, electricity should not be used for heating a house if logs in a fireplace work for the same. This is because by using electricity the energy that has been previously used for ordinary fuel in electricity is wasted [2].

II. EMERGY

The concepts of quantity, energy quality, and transformity have been defined in the previous section. Then, emergy is now to be defined. The holistic environmental and economic efficiencies of an industrial process can be assessed by a variety of techniques, such as life cycle analysis, exergy analysis, ecological footprint,etc. [3].

The method of emergy analysis is a method of environmental accounting based on energy, which expresses all the inputs of the process (energy, natural resources, services) and outputs (products or services) in solar equivalents. Thus, emergy is defined as *the solar energy that is used directly or indirectly for generating a product or service* [3, 5].That means emergy is the total quantity of solar energy necessary to generate that good or product. The units of emergy are the solar equivalent joules (seJ). It is the measure that unifies the consumption of material, energy, and social resources spent for obtaining products or services.

It is all the mentioned above the reason why emergy means "energetic memory".It consists on calculating the cost (in energetic terms) of materials and resources used in generating certain products or services (memory of how much sun is used in creating products or services).Hence, any type of energy that is contained in a product is, in theory, solar energy that has gone through a series of transformation processes. This is why solar energy has been taken as the basis of all emergy calculations.

III. EMERGY ALGEBRA

Aggregation requires transforming all the different qualities of energy or mass to the energy quality of reference (by definition, emergy).Also, it is necessary to know the position in the hierarchy of every element that is involved in the process. Therefore, *transformity* is used to overcome these concerns. Transformity was previously defined as the quantity of solar energy that is necessary to generate a unit of better quality energy or mass. In other words, this is the required emergy for generating a unit of product.It will make possible to transform the different types of energy or mass that were used in terms of solar energy (seJ) equivalents. This factor of transformity would be used as an equivalence value (UEV), that would also indicate at what level is a component in the quality hierarchy.

In algebraic terms, it is found that:

$$E_m = T \times E \qquad \textbf{Eq. 1}$$

Where:
$E_m(seJ) = Emergyoftheproduct$
$T\left({}^{seJ}/_{Unitofenergy}\right) = Transformity$

$E\ (Unitofenergy) = Energy$

Similarly for the case of mass,

$$E_m = T \times M \qquad \textbf{Eq. 2}$$

Where: $E_m\,(sej) = Emergyoftheproduct$
$T(sej/unit) = Specifictransformity$
$M\;(unitofmass) = mass$

Likewise, transformity can be calculated as:

$$T_r = E_m/E \text{ ó } T_r = E_m/M \qquad \textbf{Eq. 3}$$

Transformity is expressed as solar energy joules per joule (SeJ) per kilograms (kg) or monetary value ($) of product (seJ/J, seJ/kg, seJ/$). This factor is an inherent quantity for each type of energy and material.These values indicate the amount of solar energy that has been spent for obtaining one energetic unit of product. In addition, this allows expressing all the types of energy and material involved in terms of common units.

As shown in equation 3, it can be inferred that transformity is the inverse value of the energetic efficiency of the system. Low transformity means that less emergy is necessary for generating the product or service.

This is how the ***total emergy*** of a process is the sum of all the inputs (mass and energy) entering to the process, multiplied by their transformity (see equation 4).

IV. INPUTS OF THE SYSTEM

When assessing emergy, it is intended to evaluate all the energy involved in the generation of a product based on the past energy that participated in successive transformation processes. The emergy value will be related to the quantity of energy that was necessary to be used.These forms of energy are***:*** ***renewable sources of the system*** (environmental services), ***non-renewable sources of the system*** (material inputs), and ***imported sources*** to the system (money investment in production input such as human labor) [6].In this way, social, environmental, and economic aspects are involved by energy and mass flows.These different types of energy are expressed in the same unit (by the transformity factor) and aggregated [7].

Therefore, emergy analysis is an adequate method for making environmental decisions. Emergy does not only counts on the energy flows of a system, but also recognizes the quality of these energy flows, explaining the hierarchical distribution of energy in such systems [8].

V. EMERGETIC SYMBOLS

To carry out emergy systems modeling, an own language called energetic language is used. This is constituted by a whole set of symbols for different components of a system. Through these symbols, emergy flow diagrams are constructed [2, 9, 10, 11].

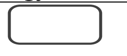
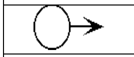
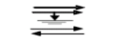
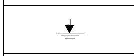
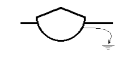
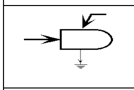
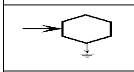
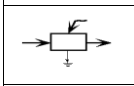
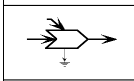
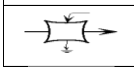
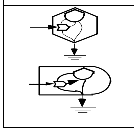
	**System boundaries**: symbol for defining the limits of a system, subsystem, etc.
	**Energy source**: They are the "focuses" located outside the boundaries of the system, and from which flows of matter and energy set off within it.
	**Energetic path**: It connects the various system components. Reflects the transfer of energy, materials or information between them.
	**Heat drain**: scattered energy that can not be reused. It represents the dissipation of energy into heat that accompanies all transformation or accumulation processes.
	**Depot**: it is where energy, money, services, and information are stored, whose use rates are higher than those of its renewal.
	**Producer**: unit that through certain processes, collects and transforms low-quality energy by concentrating it; it means, it makes products.
	**Consumer**: unit that consumes more energy than it produces, but provides services with greater emergy.
	**Black box**: a unit representing any process without explaining how it functions, which works according to one or more entries, delimiting a subsystem within a larger system.
	**Interaction:** Convergence of flows of different types (intersection of two or more flows), which, by the action of various processes, results in more quality flows.
	**Activation (switch or diversion):** indicates the start or end of a process resulting from the interaction of one or more inputs, such as fire or the pollination of flowers.
	**Feedback:** the line that returns to the left of the diagram is called return or supply, either for a production or consumer subsystem.

Table 1. Emergy symbols.

VI. FLOW DIAGRAMS

Flow diagrams are elaborated using the symbols of emergy terminology. A flow diagram is a conceptual model of the reality. This constitutes a fundamental initial step of emergy evaluation, as well as the initial step for some other system analyses [12]. Further results will depend on this model is defined. These can be less or more detailed results. But, depending on the objective and the type of socio-ecosystems that have been addressed. Despite the fact it constitutes a simplification of reality, it makes it possible to address complex systems, establish their main components and determine their control factors and guidelines. [13].

Conceptual modeling through emergy symbols clarifies the objectives, organizes and gathers available data, and exposes information gaps. Besides, it represents the components of a certain problem, as well as to reflect on the nature of them and their relationship with others in terms of flows of mass, energy and information. Moreover, it may even lead to the direct production of simulations or indexes for comparisons among systems [3, 14].

Emergy diagrams display all the energy sources that enter to the system: *renewable sources **(R)**, non-renewable sources **(N)**, imported sources or economic resources **(F)***.Their final output is the total quantity of solar energy which has been utilized for generating a particular good or product. As seen in Figure 2, the accounting of the total emergy of the process is shown in Equation 4.Where this is the sum of each of the resources entering to the process and multiplied by their transformity values.

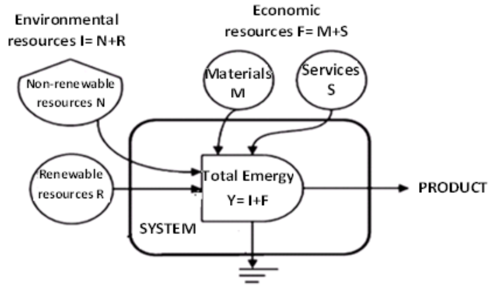


Figure 2. Emergy flow diagram

$$E_m = R * T + N * T + F * T \qquad \textbf{Eq. 4}$$

VII. EMERGY AND SUSTAINABILITY

In other words, a product emergy value is not the energy contained by this product, but the quantity of solar energy that has been used in the creation of such product.

As it has been stated in previous sections, the emergy analysis separates the entries of renewable sources (***R***) from the entries of non-renewable sources (***N***), and also from the imported entries (***F***).This meanss that the emergy is a function of the environment, the energy, and the economics.It is the compatibility between the economic aspects (maximum productivity) and the environment. Therefore, the best relationship is having the highest productivity with a minimum negative environmental impact.

These distinctions make it possible to define the emergy indicators which provide the tools for the environmental decision making in terms of sustainability. [7, 15, 16].

or a project depends mainly on the types of resources or energy that intervene and their usage. This emphasizes the usage of renewable resources rather than non-renewable ones.

Therefore, a system can be considered as sustainable as long as its energy sources prevail within time (renewable sources). Also, a system is sustainable if is able to adapt to the available energy sources, as well as to replace them in case that the original energy sources are no longer available [2]. Therefore, sustainability is intrinsic to the relation that exists between the consumption rate of the resources and to the rate at which a reservoir generates the resources.For instance, the extraction of mineral resources tends to be unsustainable since it is an activity based on non-renewable products.

In other words, the sustainability of an economic activity (in emergy terms) is function of the renewable and imported resources and its generated overload to the environment. [2].

The next indicators describe all Aspects of environmental sustainability[15].

- *Environmental Loading Ratio, ELR*: As described in Eq. 5, this is the environmental load index, which refers to the relation between the entries of non-renewable resources (*NR*) to the system, plus the imported resources (*F*) over the renewable inputs (*R*).

$$ELR = (NR + F)/R \qquad \textbf{Eq. 5}$$

Low values of ELR (<2), indicate that processes have a low environmental impact, or they count on a great area to dissipate their environmental impact.When ELR>10, there is a high environmental load, and when 3<ELR<10, the impact is considered as moderate. This index is high for systems with high non-renewable entries or with high releases to the environment [17], and also for highly technological processes.

- *Emergy Yield Ratio, EYR.*This is the emergy performance index; it indicates the relation between the total emergy inputs to the system over the imported resources (See Eq. 6).

$$EYR = (R + NR + F)/F \qquad \textbf{Eq. 6}$$

This index is used for estimating the dependence of the process on the imported or purchased resources, and also for showing the contribution of the local natural capital in the economy of the regionor to the process.

Low EYR values indicate a low economic benefit and a weak market competition. On the contrary, high EYR values indicate a strong competition that the developed product has and a high economic benefit [18].

A EYR<5 indicates that during the process, a great amount of secondary raw material (e.g., cement, steel, etc.) are used. A EYR>5 indicates the use of primary energy resources and EYR<2 indicates that there is no significant contributions of local resources and are associated to processes that are almost completely manufactured [7].

- *Emergy Sustainable Index, ESI.* It is the index of sustainability and indicates the relation between the emergy performance and the environmental load index.

$$ESI = EYR/ELR \qquad \textbf{Eq. 7}$$

As described by Eq. 7, this index reflects the capacity of a system to provide products or services with a minimum environmental stress and a maximum economic benefit. [19].

When ESI <1, the process is not sustainable in long term, when 1<ESI<5, a sustainable contribution to the economy is present during medium-term periods. With ESI>5, the process can be considered sustainable in a long term. However, it is incorrect to believe that the greater this index is, the greater is the sustainability of the process, since at ESI>10 the process is considered to be underdeveloped [17].

- *Emergy Investment Ratio, EIR*. It is the emergy investment index; it is the relation between the entries of imported resource to the system over the sum of renewable and non-renewable resources.

$$EIR = F/(R + NR) \qquad \textbf{Ec. 8}$$

According to Eq. 8, the lower this index is, the lower is the economic cost of the process, so the alternative that presents a lower index, tends to be more competitive and flourishes in the market. Generally, the greater the relation is, the greater is the level of economic development of the system [20].

- *Renewability Ratio, %R*. It is the relation that exists between the entries of renewable sources to the system over the total emergy.

$$\%R = \frac{R}{(R+NR+F)} \times 100 \qquad \textbf{Eq.9}$$

The renewability factor (see Eq. 9)should becalculated during an emergy analysis when a sustainability assessment wants to be made [21]. It simply indicates the percentage of renewable emergy used by the system. Systems with a high percentage of renewable emergy have greater probabilities of being more sustainable and prevail (they have more capacity of surviving an economic stress than those which use a great amount of non-renewable emergy) [16, 22].

The previous sustainability indexes allow environmental decision making. Therefore, a process is sustainable when is energetically usable, economically profitable and environmentally friendly in an integrated way. Also, being sustainable means that the system is dependentof renewable resources and not due to non-renewable ones.

VIII. FINDINGS

Next, a methodological course is proposed for the development of the emergy analysis.

a) The unit must be delimited with defined boundaries (especially in the socioeconomic field, space and time limits) in which the exchanges of the system with its surroundings are established, since it is not isolated. A state constitutes a separate territorial unit, socially and economically, for which there are large data bases about its socioeconomic components, as well as about its environmental components. [1].
b) Once the study systems have been delimited, it proceeds to the collection, review and update of the environmental data. Data are classified in **R** renewable resources (R), non-renewable resources (**N**), and imported resources or services **(F)** [9].
c) Having already defined and limited the overall system and specific boundaries subsystems, it now proceeds to elaborate the flowchart of the system. An emergy system diagram is drawn using the emergy language symbols of ecological systems [1] to graph the green-energy components, the economic sector, resources used, and the flow of money through the system. In the emergy diagrams available data are grouped, allowing determining the flows and interactions in the system, highlighting the most relevant and revealing information gaps (interaction between components in energy terms). The modeling consists of the following parts [2]:

- Once the limits of the system have been established, the main inputs and outputs of energy are defined in it, and they were classified according to their nature (biogeophysical, economic, human, etc.), from left to right in order of increasing transformity around the symbol of the system limits.
  - The internal components of the system are specified as well as their relationship with the inputs and outputs of energy. Also, putting careful attention to integrate all the elements of the system that regulate the processes constituting its own functionality.
  - The money flows are included, corresponding to the economic use that some of the system flows may have, as well as the money inputs that move some of their own socioeconomic components.
  - Degradation is considered corresponding to the second law of thermodynamics (there is no one hundred percent efficiency in the transformation of energy).
  - The diagram is simplified according to the objectives of the study by adding categories to the level of detail that is desired to be carried out.

d) The construction of an emergy synthesis chart follows, which is generated based on the information of the flow diagram. There, the emergy quantities, their different components and their emergy monetary values are calculated (macroeconomic value) [9] as described inTable 2.

The first column in Table 2 refers to the order in which each of the flows is located. Second column is the name of the item or flow that is evaluated and appears, with the corresponding terminology, in the flow diagram.Besides, in each column each flow is classified as a renewable, non-renewable or imported resource. Next to this column, the corresponding units of each flow appear, whether in joules, grams or dollars, if it refers to energetic, mass or monetary flows respectively. The third column 'data' contains the values of the calculations that are done for each flow, which is calculated by using the formulas displayed in the reference [1]. All these disparate factors will have some common standardized metric. This is why in the fourth column "transformity" the emergy was placed as a unit or which is known as factor of transformity (transformity or specific energy), which transforms the figures in the third column into the figures of the fifth column (SeJ). The previously calculated and tabulated transformity values are employed for each flow in previous studies.

	Ítem	**3**	**4**	**5**	**6**
	Renewable resources				
1	Sun	**A**	**B**	**A*B=C**	Em_1/EMR
2	Rain	xx.x	xx.x	Em_2	Em_2/EMR
	Non renewable resources				
3	Petroleum				
	Imported Resources				
4	Machinery				
n	Umpteenth item	**xx.x**	**xx.x**	$\mathbf{Em_i}$	$\mathbf{Em_i/EMR}$
	System Outputs				
	Manufactured products	$XX.X$	$\sum_n^1 Emi/_{xx}$	$\sum_n^1 Em$	$EMR = \sum_n^1 Emi/_{PI}$
	TOTAL EMERGY			$\sum_n^1 Em$	

Table 2. System emergy calculation.

3. Data (units/year)
4. Transformity (seJ/unit)
5. Solar emergy (seJ/year)
6. Macroeconomic value Em$ ($/year)

Subsequently, in the fifth column, the emergy of each flow was calculated to have it expressed in some common and standardized units, by the use of these transformity values. The emergy of each flow is equal to the energy, mass or money over its transformity. In this way, all the flows have comparable units and the different qualities of energy have been pondered by using transformity data.

Finally, in the sixth column the "macroeconomic value" is calculated, or the amount of economic activity moves due to a determined flow or emergy supply, and it is calculated by dividing its emergy by the amount of the average economic activity.

Last rows are set aside for the products of the system (exporting, population, monetary products, etc.), and calculations related to their transformity, total emergy, etc.

This table has therefore accounting (value and estimated price thereof) of all components of the analyzed environmental system [1]. As a result of this procedure is a set of indices and weights suitable for the formulation of policies and environmental decision making [23].

e) Once the emergy data has been obtained, it proceeds to calculate the emergy indexes (Eqs. 5-9) which provide information on different characteristics of the studied system. These indexes are support for the management and assessment of sustainability of the system within the method criteria [7, 17].

IX. CONCLUSIONS

The emergy analysis is a quantitative assessment technique which determines the quantity of directly or indirectly used energy during a certain process for generating different quality resources, services, and products. [1]. It can be considered as an environmental management system evaluation. Also, emergy assessment allows estimating the values of different components from the system (accounting) and will define some conditions or sustainability values for environmental decision making.

REFERENCES

[1] **Odum, H.T.***Environmental accounting: Emergy and Environmental Decision Making*, (J. W. and Sons, Ed.), New York, 1996.

[2] **Lomas, P. L., Donato, M. D. and Ulgiati, S**. La síntesis emergética: una valoración de los servicios de los ecosistemas con base termodinámica. *Revista Ecosistemas, 16*(3), 37-45, 2007.

[3] **Odum, H. and Odum, B**. Concepts and methods of ecological engineering. *Ecological Engineering*, *20*(5), 339-361, 2003.

[4] **Sciubba, E. and Ulgiati, S.** Emergy and exergy analyses: Complementary methods

or irreducible ideological options. *Energy*, *30*(10), 1953-1988, 2005.

[5] **Vassallo, P. and Fabiano, M.** Emergy required for the complete treatment of municipal wastewater. *Ecological Engineering*, *35*(5), 687-694, 2009.

[6] **Soibelzon, H. L.** Aspectos de la sustentabilidad relacionados con la energía eléctrica. (pp. Tomo III: pp. 181 – 206.). Buenos Aires, 2007.

[7] **Brown, Mark T., Raugei, M. and Ulgiati, S.** On boundaries and "investments" in Emergy Synthesis and LCA: A case study on thermal vs. photovoltaic electricity. *Ecological Indicators*, *15*(1), 227-235, 2012.

[8] **Arias, M. E. and Brown, M. T.** Feasibility of using constructed treatment wetlands for municipal wastewater treatment in the Bogotá Savannah, Colombia. *Ecological Engineering*, *35*(7), 1070-1078, 2009.

[9] **Álvarez, S., Lomas, P. L., Martín, B., Rodríguez, M. and Montes, C.** La síntesis emergética ("emergy synthesis"). Integrando energía, ecología y economía. [Monografia]. Universidad autónoma de Madrid España, 2006.

[10] **Lomas Huerta, P.** Aportaciones de la síntesis emergética a la evaluación multi-escalar del empleo de los servicios de los ecosistemas a través de casos de estudio [PhD Thesis]. Universidad Autónoma de Madrid, Facultad de Ciencias, Departamento de Ecología, 2009.

[11] **Manyà, J., Gonzal, A., Sánchez, J.L., Arauzo, J., Rocha, J.D., Mesa and J.M.** Gasificación de fangos de depuradora en lecho fluidizado: influencia de la temperatura y de la relación estequiometria. Trabajo investigativo Universidad de Campinas y Zaragoza. Brazil-España, 2005.

[12] **Odum, H., Brown, M. and Brandt-Williams, S.** *Handbook of emergy evaluation. Center for Environmental Policy. Environmental Engineerging Sciences*. (U. of F. Gainesville, Ed.). Florida. Retrieved from http://www.ees.ufl.edu/cep/emergydownloads.asp, 2000.

[13] **Sklar, F. H., Constanza, R. and Day, J. W.** *Model conceptualization. In Wetlands and Shallow Continental Water Bodies*. (B. . Patten, Ed.) (SPB Academ.), 1990.

[14] **Lapa, N., Barbosa, R., Lopes, M. H., Mendes, B., Abelha, P., Boavida, D.and Gulyurtlu, I.** Chemical and ecotoxicological characterization of ashes obtained from sewage sludge combustion in a fluidised-bed reactor. *Journal of hazardous materials*, *147*(1-2), 175-83, 2007.

[15] **Castellini, C., Bastianoni, S., Granai, C., Bosco, A. D. and Brunetti, M.** Sustainability of poultry production using the emergy approach: Comparison of conventional and organic rearing systems. *Agriculture, Ecosystems & Environment*, *114*(2-4), 343-350, 2006.

[16] **Cohen, M. J., Brown, M. T. and Shepherd, K. D.** Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis. *Agriculture, Ecosystems & Environment*, *114*(2-4), 249-269, 2006.

[17] **Cao, K. and Feng, X.** The Emergy Analysis of Multi-Product Systems. *Process Safety and Environmental Protection*, *85*(5), 494-500, 2007.

[18] **Zhou, S. Y., Zhang, B. and Cai, Z. F.** Emergy analysis of a farm biogas project in China: A biophysical perspective of agricultural ecological engineering. *Communications in Nonlinear Science and Numerical Simulation*, *15*(5), 1408-1418, 2010.

[19] **Zhang, X., Deng, S., Zhang, Y., Yang, G., Li, L., Qi, H. and Xiao, H.** Emergy evaluation of the impact of waste exchanges on the sustainability of industrial systems. *Ecological Engineering*, *37*(2), 206-216, 2011.

[20] **Zhang, L. X., Yang, Z. F. and Chen, G. Q.** Emergy analysis of cropping–grazing system in Inner Mongolia Autonomous Region, China. *Energy Policy*, *35*(7), 3843-3855, 2007.

[21] **Agostinho, F., Diniz, G., Siche, R. and Ortega, E.** The use of emergy assessment and the Geographical Information System in the diagnosis of small family farms in Brazil. *Ecological Modelling*, *210*(1-2), 37-57, 2008.

[22] **Rydberg, T. and Haden, A.** Emergy evaluations of Denmark and Danish agriculture: Assessing the influence of changing resource availability on the organization of agriculture and society. *Agriculture, Ecosystems & Environment*, *117*(2-3), 145-158, 2006.

[23] **Brown, M. T. and Ulgiati, S.** Emergy analysis and environmental accounting. *Encyclopedia Energy*, *2*, 329–354, 2004.