Ecological Modelling 368 (2018) 336–343

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Exploring approaches and dimensions of human transformity through an educational case

Daniel M. Lupinacci[a,b], Silvia H. Bonilla[a,*]

[a] Post-graduation Program on Production Engineering, Paulista University (UNIP), Sâo Paulo, Brazil
[b] Federal Institute of Education, Science and Technology of Southern Minas Gerais, Inconfidentes, Brazil

ARTICLE INFO

Article history:
Received 28 October 2016
Received in revised form
15 September 2017
Accepted 16 September 2017

Keywords:
Emergy
Human labor
Environmental accounting
Human transformity
Teaching

ABSTRACT

Human contribution regardless of its form (manual, skilled or intellectual work) is always present in productive systems in the role of adding value to lower transformity materials and energy. Calculation of human transformity within emergy accounting methodology deserves more discussion due to the complexity and variety of aspects that human activities reflect. Two approaches identified in the literature for human transformity evaluation were adopted as the background to develop the line of thinking and organize discussion. The discussion is developed through the study of an English language school located in Brazil where two models were applied to determine the transformity of the entering students and teachers. The first model to calculate transformity is based on the educational attainment, in an analogous way to Odum's approach based on energy hierarchy. For the second, a cyclic model to calculate teachers' transformity, it was assumed that they acquired the English knowledge in the same school where they are currently teaching. It was recognized that human contribution manifests different dimensions, the activity, the temporal and the spatial dimensions. The dimension considered strongly influences the way human flows captures the inputs and how transformity is calculated. It is expected that the recognition and discussion of the influence of the dimension considered to calculate human transformity values, will contribute to further methodological development. Values of transfomity that emerged from the cyclic model better capture the dynamic of the converging resources and can feed the transformity database for future emergy calculations.

1. Introduction

Activities performed by humans are fundamental to add value to productive systems due to their high quality in emergy terms (Campbell and Lu, 2009). The term value here refers to "real value" similarly as in Odum (1996) when refers to "real wealth". That is means to add high quality human inputs (in the form of manual, skilled or intellectual work) in order to transform low quality materials and energy flows. In this case the concept of value is ecocentric, not anthropocentric. Emergy is per se an "existence value" as stated by Ju and Chen (2011), since it emphasizes the producing procedure of natural contributions, donated from the supporting ecosystems and the biosphere.

Emergy is the available energy of one kind previously used up directly or indirectly to make a service or product (Odum, 1996). Emergy accounting gives a value to services and products by converting them into equivalents of one form of energy, i.e., solar energy; its unit is the solar emjoule. The solar emergy of all the resources (also including human labor, services and information flows) is calculated by multiplying their energy flows, expressed in joules (J) by the conversion factor, defined as transformity (Odum, 1996). Extensive work has been performed for calculating the transformity values of a great part of material and energy resources valuable to society.

When human activities interact with materials, energy and other inputs their emergy contribution generates higher quality products. According to Odum (1996) transformity values reflect the hierarchical level of a system in the biosphere, comprising from natural to societal systems. Abel (2010) states that the great majority of human transformity values are larger than those corresponding to other products, fact that reflects the high quality of human inputs. A significant portion of the human emergy flows to a system was built up by the past use of global resources that converged into the individual in order to create the storage of knowledge, tasks and "know-how" (Odum, 1996; Campbell, 2013). Another portion emerges through the accumulated experience dur-

* Corresponding author.
E-mail address: shbonilla@hotmail.com (S.H. Bonilla).

https://doi.org/10.1016/j.ecolmodel.2017.09.015
0304-3800/

ing operation (Odum, 1996; Campbell, 2013), whereas cultural information beyond formal education has important roles (Abel, 2010). Bergquist et al. (2011) point out that labor measure should include calorie intake, knowledge and the way it is transferred as well as the cultural context, since labor is task and place-specific. The contribution of informal knowledge is also considered by Falkowski et al. (2015) who explored traditional ecological knowledge in traditional communities emergy terms.

We share the same opinion with Kamp et al. (2016) who affirm that there is no agreement on the calculation method for labor and deeply explored the topic in terms of direct and indirect labor upstream in the associated chain of energy transformation. We think that emergy calculations involving high quality human work deserve more discussion. Our purpose is to contribute to the further development of this methodology by using an English school located in Brazil as the focus of discussion. The system involves energy, materials and intellectual work, as well as knowledge that must be maintained and transmitted to the students. Since transformity is system-dependent and considering that the work performed by humans is placed at the higher extreme of the energy quality spectrum, the selection of the transformity approach and other considerations will strongly affect final results. The case under study deals with the necessity of calculating the transformity of the human inputs (entering students and teachers) to carry out the emergy accounting of the system which has as the main product students after one year of classes' attendance. Through the calculation of the emergy support that converges to students after a year of class attendance, some questions arise that were explored throughout the work. First, two different approaches that addressed human transformities determination were identified and discussed in order to offer a theoretical background to sustain the research. With such approaches in mind, we attempt to explain the limitations that arise when adopting transformity values that emerged from the first approach to be used to carry out calculation under the second approach. The adoption of such a measure requires methodological considerations that include the clearly establishment of the characteristics of human labor in terms of activity, spatial and temporal dimensions. For this purpose the school, a human-intensive system that relies on human inputs and also has a human outflow as the main product, supplies the empirical case. Finally, a cyclic model, where teacher knowledge was acquired at the same English school they are currently teaching was proposed as an alternative procedure to calculate the transformity of teachers. It is concluded that the different dimensions of human activities that were revealed during literature revision and throughout the development of the research, permeate the whole discussion and will direct the calculation of human transformity.

2. On human transformity approaches

Two approaches emerge from the literature devoted to human transformity calculation. Abel (2011) had already stated that emergy analyses generally take two most common forms: national emergy analyses and process analyses. Also two approaches frameworks were identified in the literature revision that will direct the discussion. The two approaches classified the fundamental works that deal with the conceptual framework on human transformity evaluation.

2.1. First approach: focus on hierarchical human "scales"

This framework is based on the assumption that the emergy flows of the universe are organized in an energy transformation hierarchy as stated by Odum (1996). The total emergy flow of a nation, state or region, is assigned to each hierarchical "level" of a human scale. When it is not desired to evidence distinct hierarchical levels, each member of the whole population is considered as an "average" located within a unique human level. It is applicable when there is no specific skill, or level of knowledge, education or experience to be represented.

Ulgiati et al. (1994) accounted for the emergy of Italy and calculated the transformity of human labor in agriculture and industry sectors by the attribution of the entire solar emergy of Italy to its total population. Neither scales nor differentiated human levels were considered thus resulting in only one level of undifferentiated people. The solar transformity, calculated by the authors to reflect untrained workers equals 7.38×10^6 sej/J. Analogous consideration was made for unskilled labor of a bamboo plantation in Brazil, where the entire national solar emergy was assigned to the total population assuming a unique level of people (Bonilla et al., 2010). In this case the transformity value equals 4.18×10^6 sej/J. But differently from Ulgiati et al. (1994) where both the calculation and application of human transformity are based on macro-scale evaluation, last work uses a human transformity value calculated under macro-scale considerations to feed a micro-scale bamboo production.

When the system is perceived like a chain of production where lower levels become the basis for people operating at higher levels, the division of different levels of humans according to knowledge, educational attainment or other criteria occurs. In Odum (1996), the human hierarchy for USA population was categorized according to the attained education level. The entire emergy of the country was assigned to each level. People who attained higher levels contribute with a greater transformity. The interval ranges from 8.9×10^6 to 2.05×10^9 sej/J for preschool and legacy, respectively.

Abel (2010) raises the question if the educational attainment was the most appropriate criterion to define human hierarchy levels. He calculated the global population transformity range and human scale categorization was conducted through a mathematical relationship. The logarithmic relation adopted by Abel (2010) was based on Odum's observation regarding the one order of magnitude decrease at each step in the chain of energy transformation (Odum, 1996). Global population was thus divided in portions logarithmically related resulting in a transformity range from 7.53×10^4 to 7.53×10^{13} sej/J (Abel, 2010).

Abel (2011) calculated transfomity by assuming that a hierarchy of seven human levels logarithmically determined exists within the macro-domain of the Taiwanese county under study. However, differently from his previous work the entire emergy was not attributed to each of the seven human levels, since other processes are sharing the total emergy flow. The transformity interval ranges from 2.78×10^6 to 2.06×10^{12} sej/J.

2.2. Second approach: "process-based" calculation

While in the first approach the entire emergy is assigned to each hierarchical level, the second approach accounts for the specific inputs that enter a human system. Specific and well detailed inflows to the system need to be available. In this way, even people belonging to the same hierarchical level (according to the first approach) might require different emergy flows if their consumption, way of life, place or activities differ. The approach emphasizes a process oriented assessment when human flows are the main product of a process that receives different inputs flows (including human flows). This approach focuses on the role of people within the process.

Odum (1996) calculated the emergy to support the University of Florida. Inputs include flows from the environment, resources necessary to operate the university (such as fuels, gasoline, water, etc), students, books, faculty and maintenance. The emergy flows of the students entering the university were calculated by using the transformities of the educational levels according to the first