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Exploring approaches and dimensions of human transformity through an educational case

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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-

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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 approach (Odum, 1996). Thus, the transformity of the corresponding level was multiplied by the hours of intellectual activity and metabolic energy per hour. The outflows of the university were graduates, research, services and sport.

Brandt-Williams (2002) calculated the transformity of migrants based on the flows of food and wages that converge into an individual. The process oriented procedure considered only the flows that directly contribute to migrant life. The main products are work, sleep and play.

The transformity of educated students at an educational center in Switzerland was calculated by Meillaud et al. (2005). The products comprised educated students, publications, courses and services. Calculation was carried out by considering the portion of emergy that directly contributes to students' formation (see the authors' considerations explained in the text). The energy of educated students accounted only for intellectual activity or class attendance (1 pers $\times$ 120 kcal/h $\times$ 4186 J/kcal $\times$ 8.3 h/day $\times$ 235 days/yr). The transformity value of these students is 2.40×10^8 sej/J. The emergy flows of the entering students, as well as the faculty and technical staff were calculated using the transformity range for educational attainment levels.

According to Abel (2011), households are the fundamental units in the social structure since they represent shelter, family organization, child rearing, protection and asset storage. The system is considered as a producer of people. Essential inputs such as electricity, water and also cultural information, information from media, conversation, education, and government, among others were included. The residents of the household are inputs to the household system, and their transformity values were calculated through the first approach by considering a hierarchy of human levels. The products of the households are adults and children, and the transformity calculated was 1.50×10^8 sej/J.

Campbell and Lu (2014) calculated the emergy required to produce an individual with a given level of education in the USA within the period from 1870 to 2006. The calculation procedure included the determination of the annual emergy required support each education subsystem (elementary, secondary and college) and then summing these inputs over the actual years that an individual needed to attain that specific level of education (from pre-school to doctoral degree). Differently from Odum (1996) whose calculation implied that the entire emergy of the nation is required to sustain all the people that have attained a given level, Campbell and Lu (2014) considered that each subsystem or level has its own inputs and outputs calculated through the process-based procedure. The inputs required to run the education systems were mostly obtained from annual national database reports, and included flows of money, energy and materials, all converted into emergy flows. The transformity values for 1983 range from 22.6×10^6 to 1446.3×10^6 sej/J from preschool to public status levels, respectively. Although the authors admitted the necessity of improving calculation by applying an iterative method, the work successfully explores the dynamics of the US education system over more than 100 years.

The comparison among the papers within the second approach enabled to establish a sub-division. In this way, although all the papers share the same process-based treatment, they differ in the purpose of the study and consequently in the information that transformity captures. It is observed that the works authored by Odum (1996), Brandt-Williams (2002), Meillaud et al. (2005) and Abel (2011) assess the global resources that converged to the systems in an annual and flow basis. On the other side, Campbell and Lu (2014) (and also their earlier version published in 2009) capture the accumulative global resources to generate the product/products. In this way, human transformity calculated from those works, even expressed in the same units and calculated under the same approach represent either flow or cumulative global resources per individual, respectively.

3. Materials and methods

3.1. Background Information on the english school

The building that hosts the school is approximately 45 years old. It is located in Ouro Fino, a city of Minas Gerais State in Brazil and was originally built as a private residence. It was reconditioned and modified in order to operate as a school. It is 114.24 m^2 in area and has five classrooms, a waiting room, a front desk, a toilet and a teacher's room. There are about 300 students enrolled in the English courses. The courses are classified according to the age and English proficiency levels. Four course modalities are offered at the schools which are TOTS, KIDS, TEENS and CLASS, listed in increasing order of knowledge. The present paper focuses on the 47 students who are attending the CLASS course.

3.2. Emergy accounting and transformity

The emergy accounting methodology offers the flexibility of expressing diverse inputs on a common basis, as well as evidences the different abilities for energy to do work. A complete assessment of the methodology cannot be addressed here, but the reader may find it in Odum (1996) and Brown and Ulgiati (2004), among others.

As stated by Grönlund et al. (2004), the calculation of resource flows in emergy is corrected for their position in the energy hierarchy of the biosphere, which enables us to establish the relative influence of each item on the system.

Solar Transformity reflects the hierarchical position of an item within the biosphere, and represents the solar emergy required to produce 1 J of a product or service; its unit is solar emjoule per joule (sej/J). To establish the emergy flows every material, energy or monetary input has to be inventoried and multiplied by its corresponding transformity or Unit Emergy Value (UEV-emergy per unit) to be converted into solar equivalents of emergy. The solar emergy of the system represents the costs of capturing, concentrating and processing in space and time all the direct and indirect energy inputs to a system (Coscieme et al., 2014).

A normal procedure to calculate the transformity of the products that emerge from the system evaluation is to divide the total emergy input by the energy of the output. In the present case, the products is represented by the students that experience all the emergy inputs necessary to perform the teaching-learning activities. The system was addressed through the second approach framework. The system receives emergy from material, water, electricity and human activities.

3.3. Data and general calculation considerations

The first step of the emergy accounting consists of the identification of all the global resources necessary for the building structure. The Brazilian standard (ABNT, 2006) defines and quantifies the construction budget exclusively involved in house construction. The annual emergy was calculated from the total emergy required for construction divided by a lifespan of 50 years.

All the resources used to support the system were identified, that includes the human work performed by teachers and secretary and the emergy of students who learn through the interaction with teachers and the operational support. The system energy diagram is shown in Fig. 1.

The symbol of storage placed on the left within the system frame represents the concentration that resulted from the interaction of material and labor in construction process. In order to simplify the diagram all the materials were aggregated in a unique source symbol, independently of their origin. The detailed list is shown in Table 1. Building use, represented by a box, is the process where the house structure and the flows necessary for school operation

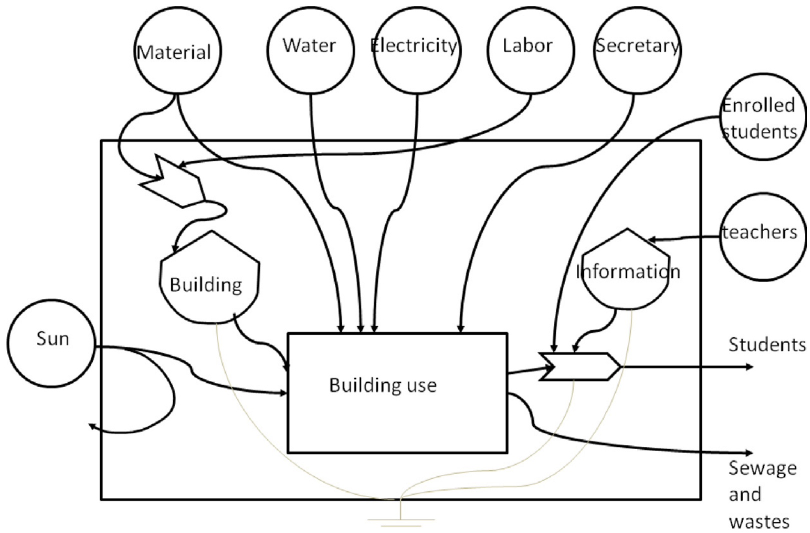

Fig. 1. Energy System Language diagram of the English language school.

Table 1
Emergy evaluation table of school building.

Items	Description	Unit	Quant. (unit)	UEV (sej/unit)	Emergy (sej)	% (sej/sej)	UEV ref.
Construction							
1	concrete	g	5.85E+07	1.97E+09	1.15E+17	28.0	a
2	steel	g	2.03E+06	5.29E+09	1.07E+16	2.6	a
3	ceramic	g	3.29E+06	3.92E+09	1.29E+16	3.1	a
4	wood	g	1.20E+06	1.13E+09	1.35E+15	<1	a
5	iron	g	1.34E+04	5.29E+09	7.09E+13	<1	a
6	plastic	g	2.77E+02	7.49E+09	2.07E+12	<1	a
7	PVC	g	2.12E+05	7.49E+09	1.59E+15	<1	a
8	glass	g	1.06E+05	4.11E+09	4.35E+14	<1	a
9	granite	g	1.12E+07	6.40E+08	7.17E+15	1.7	b
10	aluminum	g	9.18E+04	1.62E+10	1.49E+15	<1	a
11	cement	g	1.33E+07	2.52E+09	3.35E+16	8.2	a
12	clay	g	2.95E+07	2.56E+09	7.55E+16	18.4	b
13	sand	g	3.85E+07	1.70E+09	6.55E+16	15.9	c
14	copper	g	7.77E+04	7.90E+10	6.14E+15	1.5	d
15	paint	g	3.70E+05	1.94E+10	7.17E+15	1.7	d
16	labor	J	3.42E+09	2.12E+07	7.27E+16	17.7	e
	Total emergy for building construction				4.11E+17	100.0	

In order to unify global emergy budgets, all the UEVs are expressed in the adopted baseline. UEVs on the Odum (1996) baseline were multiplied by 1.28. This procedure was carried out for UEVs extracted from refs a and b. UEVs on the Odum et al. (2000) baseline were multiplied by 0.76. This was carried out for refs c and d.

[a] Brown and Buranakarn (2003).
[b] Odum (1996).
[c] Campbell et al. (2005).
[d] Pulselli et al. (2007).
[e] For fundamental school level attainment. Calculated on this paper, Appendix A.

converge. On the right, the teaching-learning process is represented by the interaction of teachers and students plus the contribution of the operational support. The main product corresponds to students who completed a year of CLASS course attendance. The softer lines correspond to the energy dissipation.

The calculation procedure required some allocations. Only the students enrolled at the CLASS course were taken into consideration. The 47 students correspond to 16% of the total number of students in the English school. Therefore the same proportion of the school operation inputs was considered. On the other side, the entire annual emergy flow derived from construction was accounted for, since it was considered that any teaching-learning process would be impossible without the whole facilities.

Teachers and entering students are represented as sources on the right of the diagram (Fig. 1).

The revised value of 12.1×10^{24} sej/yr for the emergy baseline is adopted throughout this paper (Brown and Ulgiati, 2016). In this way, all the UEVs calculated on the older baselines were corrected by multiplying by 1.28 or 0.76 whether expressed according to Odum (1996) or Odum et al. (2000), respectively. These factors correspond to the ratio between the revised and the older baselines.

3.4. Considerations for human work calculation

The emergy evaluation of human inputs and outputs of the system deserves a detailed description in order to justify the procedure adopted. The system is human intensive since it involves students that receive the contribution of teachers to improve their English knowledge. Two procedures were explored to calculate the emergy of teachers that is delivered to support teaching. The first procedure, also used to calculate the entering students' transformity, assumed that teachers and students belong to different education levels within the population (in this case, the population of Minas Gerais State). For this purpose an analogous consideration to Odum's (Odum, 1996) was adopted and the transformity of people belonging to a specific education level was calculated by dividing the total annual solar emergy supporting Minas Gerais state (calculated by Demetrio, 2011) by the number of people (expressed in total annual metabolic energy per person) in each category. Total emergy was assigned to each level of education. English teachers were considered to belong to the college graduate level, whereas students were assigned to the high school level. The calculation of transformity for teachers and entering students is shown in Appendix A.

The second procedure, a cyclic model was developed with the assumption that the teachers acquired their English knowledge in the same school where they are currently teaching. It was supposed that they studied at an equivalent of the CLASS advanced course during a period of six years. After that period, they became proficient enough to initiate teaching activities at the same English school. The equations are developed in Appendix B.

The emergy of the teaching-learning activities performed by teachers and students is calculated as the sum of the emergy delivered by teachers plus the emergy brought by the students during the class period.

4. Results and discussion

The list of inputs, their corresponding raw data, UEVs and emergy invested at school construction is depicted in Table 1.

Results in Table 1 evidence the cost of the biosphere invested in providing the structural support for the teaching-learning process. The annual value of this support when spanned within life time is 0.82×10^{16} sej and it is distributed among three main material inflows (concrete, clay and sand) and labor. The four inputs represent almost the 80% of the total (sej/sej).

Table 2 shows all the resources used to support the teaching learning process at the CLASS course for a year.

Table 2 shows the emergy necessary to run the teaching-learning process of the CLASS course. The transformity for teachers and entering students were calculated according to the first approach as explained in the section 3. In this way, teachers and entering students are located in different levels of the human hierarchy scale if educational attainment is considered as the criterion.

Human inputs in the form of teachers' labor, secretary's labor (considered as the main staff services) and contribution of students, who carry their prior education according to their educational attainment, are responsible for the main emergy contribution. Approximately 95% of the total emergy corresponds to human activities such as teaching, learning and supporting the teaching-learning process. Emergy flows corresponding to computers, electricity and construction have a small although non negligible weight within building and operation contributions.

As was previously stated the present calculation is carried out within the framework of the second approach although human transformity values shown in Table 2 emerged from the *first approach*. The same pattern regarding the use of human transformity calculated within the first approach framework in process-oriented analysis, was observed in other papers (Odum, 1996 in Florida University case; Meillaud et al., 2005; Almeida et al., 2013). Differently, Campbell and Lu (2009, 2014) adopted the salary of teachers converted to emergy and a spun-up model to get the input values. Some aspects should be addressed when calculating or adopting human transformity values calculated within the first approach to be in agreement with the theoretical assumption that supports it. The human levels or human scales selected to hierarchically organize a population have to be clearly defined and must compose an arrangement based on a real energy transformation hierarchy. If another human scale was preferred or considered more adequate to reflect the categories within the human scale as discussed by Abel (2010), the levels should be re-defined and delimited in order to avoid overlap among levels. Each person would belong to a hierarchical level if working within the assumption of the first framework. However it is not necessarily true that each human task, skill or occupation will define a human scale. In this way, the rereading of Almeida et al. (2013) raises the question about the correlation among occupations and hierarchical levels. The students entering university are considering as located into the high school attainment level, whereas professors were considered to belong to a category composed by college professors. Whether the higher education professors' category really represents a hierarchical level or it better represents an occupation portion of a broader level deserves more discussion. The number of components in each level will impact the transformity calculated within the first approach since it is assumed that the annual emergy use is necessary for each level to exist and the whole value will be divided to the number of individuals of each level.

According to Abel (2011) all the persons who reside within a process, share the total emergy on a per capita basis. The present study shows that students during attendance experience various kinds of inputs that enable school operation. The value of 2.51×10^{17} sej/year emerges from Table 2 for all the students after one year attendance. The question about if it is reasonable to calculate the transformity of emerging students from the emergy per capita value arises. Abel (2011) argues that in the tourist resorts study performed by Brown and Ulgiati (2001), transformities were not calculated for tourists, since they do not actually reside at the resorts. On the other hand, some authors have expressed the results transformity terms, even under the condition of "non residence" of students within the system (Meillaud et al., 2005; Campbell et al., 2009; Almeida et al., 2013). Neither do students reside at the school at the English school all; but it is reasonable to understand that they could experience the convergence of inputs during classes, almost in such a way as they partially reside within the process. Maybe the central questions to be answered were which the human related products of the process really mean. In a process of "producing people" as in Abel (2011), the human-product will be people's lives. For the process of tourists spending some time at the tourism destination, tourist carrying new experiences will be the human-product. Accordingly, different aspects of human activities can be highlighted and calculated in emergy terms. Grönlund (2009) addressed that the flows in systems can be expressed in terms of the quantity-quality thinking. He also mentioned that the average scientifics primarily think of quantitative measure of energy and seldom of its quality aspects. In the same way as energy which can acquire different forms, can reveal different energy density or capacity to do work, human flows also present different qualitative aspects that we define as "dimensions". Although inherently attached to human related activities, dimensions are seldom explicitly expressed in calculations. Human flows might be ascribed to at least three dimensions we were able to identify: form, time and space. The first is related to the type of activity and the abilities, knowledge or skills necessary to carry out the activity within the system. Meanwhile, human activities as well as people lives are "bounded in time". Time is shared among multiple activities during people lives or even in a day. People are also physically bounded to territory as already stated by Abel (2011), so convergence of inputs represents a convergence to "someplace" in a spatially defined way. All of the three dimensions that define the human-product were not generally considered neither evidenced in emergy accountings. Possibly, time is among the three dimensions, the most difficult to deal with in emergy terms. It seems reasonable to consider a person as "belonging to" a hierarchical scale (namely, a specific education level) in a yearly basis. Human products emerging from a specific hierarchical level seem to be a situation where people are involved full-time. On the other side under the second approach the person

Table 2
Emergy evaluation table (annual operation) of the English language school.

Items	Description	Unit	Quant. (unit/yr)	UEV (sej/unit)	Emergy (sej/yr)	% (sej/sej)	UEV ref.
Infrastructure							
1	building				0.82E + 16	3.3	a
Use							
2	Water	m^3	4.80E + 01	9.90E + 11	4.75E + 13	<1	b
3	Electricity	J	9.41E + 09	3.54E + 05	3.33E + 15	1.3	c
4	Paper	g	2.30E + 04	3.04E + 09	6.99E + 13	<1	d
5	Plastic	g	1.89E + 05	7.49E + 09	1.41E + 15	<1	e
6	Glass	g	6.69E + 03	4.11E + 09	2.75E + 13	<1	e
7	Wood	g	2.74E + 04	1.13E + 09	3.08E + 13	<1	e
8	Iron	g	5.42E + 04	5.29E + 09	2.87E + 14	<1	e
9	Computer	g	3.90E + 04	6.76E + 10	2.64E + 15	1.0	f
10	Secretary	J	1.42E + 09	3.76E + 07	5.34E + 16	21.3	g
11	Students	J	2.83E + 09	3.76E + 07	1.06E + 17	42.2	g
12	Teachers	J	5.43E + 08	1.41E + 08	0.76E + 17	30.3	g
	Total				2.51E + 17	100.0	

In order to unify global emergy budgets, all the UEVs are expressed in the adopted baseline. UEVs on the Odum (1996) baseline were multiplied by 1.28. This procedure was carried out for UEVs extracted from refs b, c, d and e. UEV in ref f since it was expressed on the Odum et al. (2000) baseline was multiplied by 0.76.
[a] from Table 1 (divided by 50 years).
[b] Buenfil (2001).
[c] Odum (1996).
[d] Meillaud et al. (2005).
[e] Brown and Buranakarn (2003).
[f] Di Salvo and Agostinho 2015.
[g] Calculated on this paper, Appendix A.

Table 3
Emergy evaluation table of the English school with teachers' inflows calculated by assuming they studied at the same school during 6 years at the advanced level.

Item	Description	Unit	Quant. (unit/yr)	UEV (sej/unit)	Emergy sej/yr	% (sej/sej)	UEV ref.
Infrastructure							
1	Construction				0.82E + 16	2.2	a
Use							
2	Water	m^3	4.80E + 01	9.90E + 11	4.75E + 13	<1	b
3	Electricity	J	9.41E + 09	3.54E + 05	3.33E + 15	<1	c
4	Paper	g	2.30E + 04	3.04E + 09	6.99E + 13	<1	d
5	Plastic	g	1.89E + 05	7.49E + 09	1.41E + 15	<1	e
6	Glass	g	6.69E + 03	4.11E + 09	2.75E + 13	<1	e
7	Wood	g	2.74E + 04	1.13E + 09	3.08E + 13	<1	e
8	Iron	g	5.42E + 04	5.29E + 09	2.87E + 14	<1	e
9	Computer	g	3.90E + 04	6.76E + 10	2.64E + 15	<1	f
10	Secretary	J	1.42E + 09	3.76E + 07	5.34E + 16	14.7	g
11	Students	J	2.83E + 09	3.76E + 07	1.06E + 17	29.3	g
12	Teachers	J	5.43E + 08	3.45E + 08	1.87E + 17	51.7	g
	Total				3.62E + 17	100.0	

In order to unify global emergy budgets, all the UEVs are expressed in the adopted baseline. UEVs on the Odum (1996) baseline were multiplied by 1.28. This procedure was carried out for UEVs extracted from refs b, c, d and e. UEV in ref f since it was expressed on the Odum et al. (2000) baseline was multiplied by 0.76.
[a] from Table 1 (divided by 50 years).
[b] Buenfil (2001).
[c] Odum (1996).
[d] Meillaud et al. (2005).
[e] Brown and Buranakarn (2003).
[f] Di Salvo and Agostinho 2015.
[g] Calculated on this paper, Appendix B.

can receive the emergy flows during a period and consequently it is only during this period of time when it is possible to control the human-product.

Meanwhile this person can represent a temporal input in another system, where he could deliver emergy through interaction and profit from emergy support from this location for a period of time. Sometimes people are considered as actors who receive or deliver emergy flows for a while.

Thus, transformity of the students after one year of class attendance, calculated by considering the time period the students can access, control or have been supported by the convergence of the inputs is 8.87×10^7 sej/J. The value is twice their transformity when they began the CLASS course.

The second model proposed to calculate teachers emergy inflows assumes that the teacher who is currently teaching at the school studied there in order to acquire the necessary level of English knowledge to become a teacher. This scenario shows an endogenous and cyclic way to calculate human transformity (shown in Appendix B). The model adopted a period of 6 years at the advanced CLASS course or a similar.

Table 3 lists the necessary inputs to support the CLASS course during a year; in this case teachers emerged from the same school. Some differences arise when comparing Tables 2 and 3. The cumulative way of addressing the inputs that contribute to teacher formation led to emergy values around twice those calculated through their educational attainment. Whereas the former accounting shows that entering students represents the larger contribution, Table 3 evidences that the teachers' labor is the higher contribution.

An important aspect to notice in both models is the large contribution of human flows when compared to the other emergy flows as a consequence of large human transformity values. As stated by

Campbell et al. (2011), human service is often engaged to add value to lower quality materials.

The transformity of the students after one year of classes attendance is 1.28×10^8 sej/J, that corresponds to 3.5 times the value when they began the course.

5. Conclusions

Evaluation of human transformity is a topic that deserves attention and deep exploration due to the essential contributions of human activities to all ecological, economic and social systems. This fact is qualitatively noticeable in terms of larger transformity values for humans' flows when compared with other inputs. The study evidences the lack of a unified way of accounting for human activities. The hierarchical levels approach, exemplified by Odum's categorization of population in educational levels, deals with average values which may not reflect the real and particular situation of a specific system. Even so, it is the most adopted approach to calculate human inputs, regardless the spatial scope of the system. The adoption of that approach for quantifying human inputs studied under the process oriented framework does not capture the specific convergence of resources. It is argued that human transformity is activity, time and place-specific so it seems necessary to clearly establish the systems conditions and the characteristics of the human work being performed to accomplish accurate evaluations. Calculating the transformity of English teachers by the cyclic model assuming their endogenous formation within the system could better capture the dynamic and the resources that were directed to produce teacher's knowledge. Transformity of students after one year of class attendance increased twice or 3.5 times depending on the model used to calculate teachers' transformity. The endogenous or cyclic model, assumed that the emergy accumulated during the period of 6 years that supported their English learning process is the best estimate of the transformity of the teachers' work.

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Appendix A.

Table A1

Table A1
Calculation of teachers and entering students' transformity. A daily intake of 2500 kcal/day was considered.

Attainment	Numbers (E+06 indiv.)	Energy per level (E+16 J/yr)	Transformity (E+07 sej/J)
Preschool (Total)	19.36	7.40	0.95
Fundamental school	8.66	3.31	2.13
High-school	4.90	1.87	3.76
College grad.	1.30	0.50	14.06

Transformity values were calculated by dividing the total annual solar EMERGY use of the State of Minas Gerais by the number of people in the education level and the annual metabolic energy per person. Total solar emergy of Minas Gerais (year considered 2011) is 7.03×10^{23} sej/year. For the high school level the transformity is: 7.03×10^{23} sej/year/(4.90×10^{06} individual $\times$ 2.500 kcal/day $\times$ 365 days/year $\times$ 4186 J/kcal) = 4.97×10^{07} sej/J.

Appendix B.

The rules of the emergy algebra establish that the emergy of products is equal to the sum of the inputs. The model assumes that a teacher is formed after six years of advance course attendance at the same school where he is actually teaching. This means that the infrastructure as well as the other supporting resources are analogous to the ones in Table 2, but they were considered for a period of 6 years in order to attain the necessary level of English knowledge.

The first year of the teacher formation process is represented as Em_{stout1}, since they are still students that concluded the first year of the advanced course.

$Em_{build} + Em_{operation}$ corresponds to the annual emergy flows of building and operation, this latter includes teachers and secretary labor (accordingly to the first model considerations for transformity calculations); it equals 1.45×10^{17} sej/yr (Table 2).

Em_{stin1} corresponds to the emergy of students entering the school; the value is equal to the value considered in the first model. It is 1.06×10^{17} sej/yr according to Table 2.

$$Em_{stout1} = Em_{build} + Em_{operation} + Em_{stin1}$$
$$Em_{stout2} = Em_{build} + Em_{operation} + Em_{stout1} = 2 \times (Em_{build} + Em_{operation}) + Em_{stin1}$$
$$Em_{stoutn} = n \times (Em_{build} + Em_{operation}) + Em_{stin1}$$

The same procedure is repeated for the 6 years, where Em_{stouti} corresponds to the emergy flow of the output students after i years of study, with i between 1 and 6. It is assumed that the $Em_{stout(i-1)}$ is the entering flows of students of the i year since they have just finished the i–1 year of study.

For next calculations, the transformity value extracted from the flow of the 6th year of course attendance (Em_{stout6}) was adopted for the teachers (in Table 3).

In this way,

$$Em_{stout6} = 6 \times (1.45 \times 10^{17}) + 1.06 \times 10^{17} = 9.76 \times 10^{17} \text{ sej/yr}$$

$$SoTr_{teach} = Tr_{stout6} = 3.45 \times 10^8 \text{ sej/J}$$

Tr_{stout6} is the transformity of the students after 6 years of course attendance and Tr_{teach} is the transformity of the teachers graduated after 6 years of the advanced course.

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