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Decision making under the environmental perspective: Choosing between traditional and distance teaching courses

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ABSTRACT

Over the last 30 years, distance learning has rapidly spread in developed countries, and to niche markets in developing countries. In Brazil, approximately 5 million people are currently either achieving formal education or corporate training, or obtaining specific knowledge and skills on a wide range of subjects, via distance learning. Motivated by the ongoing expansion of the Brazilian federal chain of public schools, several new campuses, extra classrooms and distance teaching centers have been built, as a function of the intensive promotion of social inclusion by means of education, and specifically allocated budget. Concomitantly, a considerable number of papers discussing reduction of energy and materials consumption in university campuses have been published. Intended as a contribution to this discussion, this work evolves from a comparison of the implicit environmental cost – i.e. the use of natural resources as the prime-matter of infrastructural and operational material, and source of energy to human work-in forming management technicians in a classroom course, and in a distance learning course, obtained from the results of two case studies carried out at a Federal Institute campus in Brazil. The groups were selected for their relative closeness in proportion of attending students. Data were collected by means of measurements and interviews, and a synthesis of the use of natural resources by both modes was obtained by using the emergy accounting method, and then compared. The emergy method was also used to assess current use and underuse rates of the available infra-structural resources. Scenarios based on different numbers of students and teaching staff attending capacity for both modes, distance learning and classroom, were created and compared. Results point out that, under the current configurations, forming a management technician via distance teaching requires a 90% higher environmental support than via classroom teaching. The scenarios, however, do indicate a turning point.

1. Introduction

Distance teaching has been largely applied by governments and private educational institutions. Governments in developed and developing countries have recognized the importance of knowledge-based economies, which may include the creation of internationally accessible educational services. In this context, several major universities have invested in online education. In Brazil, distance teaching has experienced constant growth as a very active educational mode, sought after by educational institutions, corporations, and freelancers for formal education, personnel training, and by the general public searching for free-course offerings on a widely assorted range of subjects and purposes. According to the Brazilian distance teaching census – Censo EAD.BR 2015-, published by the Brazilian Distance Teaching Association (ABED, 2015), over five million people, among students and workers, subscribed to a distance-taught course that year, twenty percent of which being regular formal courses. Such figures may explain why the Brazilian government perceives distance teaching as a feasible alternative in promoting social inclusion by means of public formal education for citizens living in areas unattended with a physical public educational institution offering regular, vocational or college education. However, there are several other reasons that may be considered when deciding to implement a distance-learning course. In many countries, demand for places in conventional education systems far exceeds supply. In these circumstances, distance learning can provide quality education to a large number of students. Also, in remote or sparsely populated areas,

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where it is not economically possible to provide quality education opportunities through conventional institutions, distance learning may fill the gap, avoiding investments for the construction and maintenance of educational facilities. Finally, the more selective, restricted or expensive the conventional education system, the greater the need for an education system that promises replacing high labor and maintenance costs with low cost technology, promoting social equity. In Brazil, with the expansion of the federal secondary/technical integrated public education chain, huge investments have been made in the reformation of facilities in existing campuses, and construction of new ones, throughout the country. According to the Brazilian Ministry of Education and Culture website, the number of Federal Institute units increased from 354 in 2010, to 562 in 2014. Technical vocational courses integrated with high-school curricula, and post-high school vocational programmes are taught in the campuses and remote units arranged by means of partnerships between institutions and municipalities. Distance learning has also been one of the most convenient and sought options, concerning citizens' inclusion in the public education system, and the chain of Escola Técnica Aberta do Brasil (Open Technical School of Brazil) – E-Tec-support units finds itself under a huge expansion process nationwide. These units host many distance-teaching vocational courses, with large numbers of students enrolled. In this context, one of the arguments used in favor of distance learning is the reduced investment in building facilities, which would result in reduced energy and resource consumption.

Considering that universities energy and material consumption can be significantly reduced by effective use of organizational and technical measures, several papers have exhaustively discussed how to manage and reduce the environmental impact of conventional educational institutions. Concerning decreasing the environmental impact of campuses' operations, many papers describing the different experiences taken by educational institutions have been published. Some emphasize the potential for educational institutions to reduce waste disposal and/or energy consumption, while others discuss the challenges these institutions face in implementing waste management. At Rhodes University, for example, the use of paper was evaluated in order to increase recycling rates (Amutenya et al., 2009). The Mexicali University campus in Baja California and the Universidad Autónoma Metropolitana characterized their waste for implementing waste management programs based on recovery, reduction and recycling (de Vega et al., 2008; Espinosa et al., 2008). The University of Osnabrück published a procedure to be used by other institutions built upon Life Cycle Assessment (Viebahn, 2002) and the University of South Carolina developed the Sustainable Universities Initiative to integrate sustainability into educational institutions (Barnes and Jerman, 2002). Velasquez et al. (2006) developed a comprehensive managerial framework that offers an approach whereby people responsible for Higher Educational Institutions (HEI) sustainability initiatives may progress to achieve a more sustainable university. Additionally, a model providing a cost effective strategy for the implementation of an Environmental Management System (EMS) was published by Savely et al. (2007a), which was in response to the need for guidance for U.S. colleges and universities. These authors reported on results of a survey that provided a broad overview of the status of implementation of EMS at colleges and universities in the U.S. (Savely et al., 2007b). Alshuwaikhat and Abubakar (2008) provided systematic recommendations for reducing the negative impacts of HEI by highlighting the importance of integrating the EMS with public participation and social responsibility, and by promoting sustainability in teaching and research. Clarke and Kouri (2009) evaluated six different certified and uncertified waste management programs and observed that certified programs do not result in greater improvements in environmental performance as compared to uncertified ones, and recommended that academic leaders worldwide should continue to reduce their environmental impacts and develop new tools to help them on their journey. Tan et al. (2014) summarized the status of green campus development in China including all the initiatives to conduct the energy and resource efficient campus analyzing the possible approaches to promote the green campus development and initiatives of low-carbon campuses.

Several evaluation metrics were used to evaluate campuses' environmental performance. Sinivuoria and Saari (2006) used upstream indicators to examine the extent of natural resource use in two university buildings in Finland using the '*material input per unit of service*' method. This study provided valuable insights for reducing resource use of university buildings considering design, construction and use of educational buildings. Life Cycle Assessment results documented that heating and construction of buildings were responsible for the largest quantity of environmental impacts at the Engineering Campus of the University of Maribor (Lukman et al., 2009). Smyth et al. (2010) claimed that the characteristics of an institution's solid waste stream is the first step toward enhancing the sustainability of a waste management plan, and provided recommendations to the senior university council on strategies for improving the overall sustainability of the campus waste management program. Vásquez et al. (2015) evaluated the greenhouse gas emissions generated by Chilean universities where the main contributors were student commuting, staff commuting and electricity consumption. The most effective action proposed to reduce gas emission was related to students using bicycles rather than motor vehicles. The Carbon footprint of student behavior for a sustainable university campus was also analyzed in China (Li et al., 2015). These authors recognize university campuses as ideal places to examine these carbon mitigation strategies due to characteristics like their long planning timeframes, centralized organizations, and dense populations. Carbon footprint calculations were used to identify actions the university could take to reduce emissions. Jeong et al. (2015) proposed a model for predicting environmental impacts of educational facilities in the project planning phase based on the assumption that the project planning phase affects the whole building life cycle. The proposed model intends helping architects and facility managers to estimate environmental impacts of educational facilities.

Despite extensive literature dealing with campuses greening and implementation of EMS, most papers presenting assessments for decision-making processes and subsequent actions to be taken only deal with a part of the problem. However, there are some indicator-based tools designed to document the greening of the campuses and inclusion of sustainable development into curricula. The Graphical Assessment of Sustainability in Universities (GASU) was developed and tested by Lozano (2006a,b) based upon the Global Reporting Initiative applied to educational institutions. This tool was designed to facilitate analysis, longitudinal comparison and benchmarking of universities' sustainability efforts and achievements. It provides a concise graphical overview of indicators used by the GRI. GASU was designed to provide charts by which the user can score all indicators of each dimension economic, environmental, social and educational that are or are not incorporated into each course or curriculum. However, according to Leal Filho et al. (2009), although GASU can also be used to focus upon curricula, it provides a limited analysis. Lozano also developed the Sustainability Tool for Auditing University Curricula in Higher Education (STAUNCH©) system that assesses the extent to which a university's curricula contributes to education for Sustainable Development (SD), and provides consistent and comparable auditing that can be used to compare progress at different institutions (Leal Filho et al., 2009; Lozano, 2010; Lozano and Peattie, 2011). Disterheft et al. (2016) proposed an indicator-based model, INDICARE, to include participatory approaches in assessment procedures within higher education's sustainability initiatives. INDICARE follows an ecocentric perspective and provides a preliminary set of thirty indicators and practices, grouped in three categories of context, process, and transformation.

Emergy (spelled with an “m”) environmental accounting (Odum, 1996) is a method based upon the general systems theory and the laws of thermodynamics. By using solar energy Joules as a common unit, it can quantify different energy types used by a production system to make a service or a good, and offers a different perspective in assessing educational systems. Students learn from interacting with the infrastructure, classmates and teachers to absorb new information (Oliveira and Almeida, 2013, 2015). This new absorbed information is supported by and adds to the students' previously acquired information load. The method was first used to evaluate the “greening” of the University of Florida for the year 1978 (Odum, 1999a). More recently, Meillaud et al. (2005) used emergy synthesis to evaluate energy savings from installing solar panels on the façade of a building at the Swiss Federal Institute of Technology Lausanne. Information flows in the system are represented by High School and undergraduate students' contributions. Campbell and Lu (2014) evaluated the United States educational system from 1870 to 2006. The emergy of teaching and learning were measures of the emergy required for copying and transferring information. This was calculated as the sum of the emergy delivered by education, experience of teachers, and the emergy brought by the students into the process of learning. These authors concluded that for one unit of emergy spent on education a return 10 times greater is obtained in overall benefits gained by society. Almeida et al. (2013) used emergy synthesis to assess the Engineering programme at Universidade Paulista, comparing the results to those previously obtained for the Pharmacy and Business programmes and used those results to visualize the system holistically and its relationship with the environment. Subsystems were evaluated to assist in decision making on introducing Sustainable Development concepts into curricula and establishing targets towards greening the campus.

Distance learning is presented as environmental friendlier than full-time campus-based courses. According to Roy et al. (2008) distance learning courses involve 87 per cent less energy and 85 per cent lower CO_2 emissions than full-time campus-based courses mainly due to reduction in student travel and housing energy consumption, plus economies in campus site use. Nevertheless, It should be noted how varied and contradictory some of the arguments are in favor of, or otherwise, implementing distance learning.

This paper evaluates the environmental costs of the move towards distance teaching with the aim of helping governments and institutions manage and organize the whole system, especially in dual-mode institutions, where the growing convergence between distance and classroom learning has raised questions on how to best organize the dual-mode, how and when to use one or the other, and when the use of either mode is more beneficial to the institution and the environment. Should both modes always be offered for the sake of making both options always available? Are there situations in which one option is more suitable than the other? Which mode is, in absolute numbers, the most viable? Implicit in these questions are issues related to the implicit environmental cost of each option, and these are the issues addressed in this work. The number of intended students per class, for one, is one fundamental detail considered when a course is designed; however, seats left unfilled or abandoned should imply waste of resources, from financial and natural resources invested, to teaching staff attending capacity. Calculations of the current rates of resources underuse and simulated teaching staff capacity in terms of student contingent are included in this work. The claim that distance learning poses less pressure to the environment is examined through comparisons between two groups of the course of Technical Management at the Federal Institute of Education, Science and Technology of Southern Minas Gerais, Brazil.

This work features the use of the emergy accounting method, due to its unique property of allowing for different forms of energy to be quantified and accounted for in one single accounting table, by using the solar energy Joules (seJ) as a common unit. Emergy is the available energy of one kind, previously used up directly and indirectly to produce a service or good. Emergy accounting enables for the analysis of the quantitative/qualitative contributions from the environment and from the economy to a production system, from a donor's perspective. Research carried out for this work includes studies involving emergy accounting of construction, maintenance and usage of buildings as well as transportation for students and teachers, and references on emergy accounting of information, which, according to Odum (1996), may be the most important feature of many systems.

Emergy accounts for quality differences among different forms of energy and can be used to compare the energy involved in information flows with those of energy and materials flows. The emergy per unit time is calculated using Equation (1):

$$\text{Emergy} = (\text{energy, material or information flow}) \text{ x UEV} \tag{1}$$

where UEV is the Unit Emergy Value calculated based on the emergy required to produce one unit (Joule, gram, cubic meter, or dollar) of a given resource. To derive the UEV of a resource or product, it is necessary to draw back through all the resource and energy flows that were used to produce it.

The first step of the emergy evaluation is to create an energy systems diagram, which aims to organizing thoughts and relationships between components and pathways of exchange and resource flows. The next step is to build emergy tables based on the diagrams wherein each input flow becomes a row.

As per the description above, the amount of each energy form entering the system is converted to its specific unit, - grams, cubic meters, and Joules- and multiplied by their corresponding UEV, which gives their emergy contribution in seJ per unit time. All input amounts and calculations herein are in reference to the two-year duration of both courses.

2. Methods

2.1. Building construction and use

Data on physical structure, staff, and daily usage routines of both units, including the flow of materials, electricity and water consumption, were collected at the physical facilities in Jacutinga-MG (classroom system, from here onwards) and E-Tec Support Unit hosted by the Distance Teaching Center (DTC) at the Inconfidentes-MG campus (distance learning system) through documentation, direct measurements, blueprints and interviews with university officials. All E-Tec units are standardized, except for dimensions. Certain infrastructural items are referred to as “stock” items, as they persist over time – e.g. concrete, steel, wood – and they contribute the corresponding fraction off their considered lifespan. Therefore, the depreciation rate of school buildings was used to represent the contribution of the campus infrastructure to the emergy required for the educational process. The building lifespan considered is 25 years, which corresponds to its depreciation period (Campbell and Lu, 2014). Equipment lifespan varies from 5 to 10 years (Receita Federal do Brasil, 2005). For textbooks, a 20-year lifespan was considered. Labor-related values were calculated based on average individual kilocalorie consumption per work hour, according to Odum (1996), and Oliveira and Almeida (2015).

2.2. Accessing information

Formative information is available at the learning environment in verbal, written and printed forms (classroom system) and digital form (distance teaching). Accessing the formative information requires accessing the learning environment, using a vehicle fed with some form of energy, and led by a conductor (Oliveira and Almeida, 2015). The calculation of the expenses generated by the access-to-information apparatus used by each system, in terms of use of natural resources, was therefore included in this study, as the amount of emergy required significantly affects the final emergy accounting results for both systems. In this sense, however, due to the lack of specific data on vehicles individually used to commute to the classroom unit, the use of an urban bus weighing 12.500 kg for the transportation of students and teachers living in urban or rural areas, covering a 30 km route two times a day was considered; the occasional use of private vehicles by students and teachers was, therefore, disregarded. Fuel consumption rate considered was 0,5 l_{diesel}/km (Anfavea, apud IEMA, 2013). Energy contributed by the driver corresponds to 2 h of calorie consumption a day, five days a week. Access into the Virtual Learning Environment (VLE) platform is analyzed in an analogical fashion (vehicle, energy and conductor). Calculations were based on the use of desktop computers connected to the internet. The VLE is managed by a supervisor and fed by teachers with digitalized instructions and materials. That is where the interaction between students, tutors, and the information stock occurs. The process depends on electricity and services. Average computer power consumption considered is 200 W (monitor, CPU, printer, keyboard, mouse) (ANEEL-accessed January 2013), and average daily access session duration considered is 1.96 h/student (Oliveira and Almeida, 2013). Hydroelectricity is the predominantly used electricity type in southern Minas Gerais state (Tolmasquim et al., 2010).

2.3. Information flows

The method assumes that the information transfer process requires some form of energy (Odum, 1999b), which, in educational systems, comes from teachers and tutors, who act as information carriers, along with books and general didactic material. The work delivered by professors and tutors to support information transfer is primarily a function of their knowledge and experience, which, in turn, results from the amount of support received from the environment during their school education years, in the form of Joules of expended metabolic energy. Knowledge and experience are classified in six subsequent levels (Odum, 1996, p.232): (i) preschool, (ii) school, (iii) college, (iv) post-college learning, (v) public status, and (vi) legacy. The total national emergy flow in a given year is divided by the metabolic energy expended by the inhabitants belonging in each one of those levels of knowledge and experience to obtain the UEV (seJ/J) of an individual's labor (Odum, 1996). The minimum education level required for an individual to work as a teacher or tutor of a vocational course is a college degree, with a pedagogic training. Therefore, for calculation purposes, all teachers and tutors are assumed to belong in the college (iii) level. A 120 kcal/h consumption rate is considered as the basis for calculations (Almeida et al., 2013; Oliveira and Almeida, 2015).

Teachers, books and audio-visual aids are some of the system inputs that students interact with to absorb educational information. Odum (1996) estimates that students' absorption rate of information transmitted by teachers equals 1% of their metabolic energy expended during classes. This is the percentage considered in this work, albeit Meillaud et al. (2005) and Campbell and Lu (2009) do consider 10% as a reasonable rate. Absorption rate of information from books is 10% (Norbis, 1971). The emergy of information accumulated by the students over their previous school years is also considered and accounted for, since transforming this energy form is the end-purpose of the whole process. The emergy of information circulating within the system is the outcome of the sum of all these inputs. As the output of a production system or cycle, a good or service will automatically rank in a higher position, in the energy hierarchy, than it used to while in its previous form, as a function of the accumulation of time and energy invested in its transformation process. Consequently, the emergy value per gram, Joule, cubic meter, or dollar – UEV - of such good or service will increase. Following the pattern, as an individual's intellectual formation builds up along his/her school education years in a given level of education, he/she gradually migrates to the next higher level of education and experience (Odum, 1996-page 232). The amount of energy required (or emergy accumulated) during this transformation process accounts for an increase in the UEV of the work performed by that educated professional. However, technical formation such as the one obtained from the course of Technical Management studied herein is, officially, a complementation to high-school education, therefore, based on Odum's precept, a formed Technical Manager remains in the high-school level category.

Distance learning teachers' working hours are an approximation, based on which they are paid for their work of elaborating, organizing and uploading material and correcting tests. Calculation of metabolic energy expended by tutors is based on the amount of time they dedicate to interacting with students, individually and in chat groups. Tutors' hired online-work load is 20 h per week. Procedures for information flow calculations are based on the work of Odum (1999b). The more recent UEV value for books calculated by Campbell and Cai (2007) was used as a basis for the calculation of the UEV for a technical book, which was used in the information flows calculation phase. UEV values for students' high school information and the UEV of information transmitted by teachers are based upon updated national emergy, and census data, and were, therefore, specifically calculated for this work.

2.4. Use and underuse

2.4.1. Infrastructural resources

The physical dimensions of a classroom are one limiting factor to be considered when defining the number of students it will accommodate. Once the number of seats per class is defined by the school directors' board – a decision based upon room, staff, and specifically government-allocated budget availability - and the emergy synthesis of the physical structure has been performed, a projection of the required environmental budget to offer a course in either mode is achievable, thus comparisons can be made. Further scenarios display an even wider preview panorama, which may become a useful tool in decision-making. Since the total flow of information within the system may be considered by managers as the end-purpose of the system as a whole, the contribution from all information carriers should be considered, and accounted for, when setting the emergy budget preview for a new course. The final implicit environmental cost to run a course or school can be given in a seJ/student rate. Thus, the system becomes underused the moment one student quits, as the emergy-per-student rate increases, consequently. To illustrate, the classroom group under study, originally designed to accommodate 40 students, is currently operating with 34. This indicates relative waste of originally allocated infrastructural resources, less energy saving, and a decrease in the amount of information flows. Transportation underuse is occurring, as there is no considerable alteration in diesel consumption and in energy spent by the bus driver while conducting any number of commuters, from one to its full capacity of fifty. Underuse of teaching staff service capacity is also occurring, since two 40-student groups could be attended by the same staff, without any changes in the infrastructure of the unit. The distance teaching system, on the other hand, works with groups limited to fifty students each. Given the subjectivity of the teachers' service capacity, and the non-existing relation between the expansion of the infrastructure of, and the number of students attending courses hosted by the DTC, online-tutors' attending capacity is the item that can become underused, since they are assigned a previously defined number of students to attend and interact with. In addition to the calculations of the status for both groups, scenarios were created considering the minimum and maximum number of students per class in each mode. Underuse rate percentage is herein given as the difference between the projected emergy for a given system configuration minus its actual emergy use.

2.4.2. Teaching staff maximum attending capacity

Using the classroom teaching staff full service capacity implies increasing the infrastructure, whereas increasing the number of DTC students implies increasing the number of online and DTC-based tutors. Scenarios for both systems were created, considering one teacher per curriculum subject. The number of groups the respective teaching staffs could be attending in the interim was calculated.

To assess the idle/underused work potential of the classroom teaching staff, the weekly period during which the facilities are under concession was considered. That corresponds to forty 50-min classes per week (Monday to Friday) including a 10-min intermission, in the evening shift. Considering the infrastructure availability of 20 h a week for 82 weeks, two 40-student groups could be attending simultaneously, using the same infrastructure, classroom and staff. The teaching staff, on the other hand, by fully using the available time, could be teaching five groups. However, that would require using three classrooms. One such scenario would therefore imply the construction of two extra classrooms and two extra sets of restrooms, by ABNT- Brazilian Association of Technical Norms – norm # 5626; energy and materials consumption, vehicles for transportation, and information flows would increase. Emergy of library books, technical staff, and trainees' supervisor would remain unchanged.

In distance teaching systems, variations in the amount of service performed by teachers and tutors and the increase in number of students are the main contributors to significant variations in emergy values. Those variations do not involve changes in the physical structure of a DTC. Each 50-student group is under the care of two online-tutors and one unit-based tutor. A new computer is added with every new DTC-based tutor; 19 workbooks are distributed, and a personal computer is accounted for, per student. Therefore, electricity consumption increases. Teachers' wages include pay for an estimated 20% extra-class activities, i.e. elaboration and correction of tests and exercises, random participation in online chats, occasional work with tutors, etc. For the calculations, it was considered that, in practice, attending a number of students five times larger would result in teachers' maintaining the amount of time dedicated to preparing and uploading instructional material while doubling their working hours dedicated to the extra-class duties.

3. Results and discussion

In this chapter, an Emergy synthesis of the current configuration of both courses is performed. This allows for direct comparisons between the status of both groups as for energy and materials employed in setting up and running each system, including the emergy of the information flows, and the emergy per student ratio. These results are followed by analyses and scenarios on the use and underuse of infrastructural and teaching staff resources. The results of these projections are displayed on Table 3, whereas Fig. 3 displays trend charts for systems expansion, per accounting phase. Scenarios are based on Table S1 and Table S2.

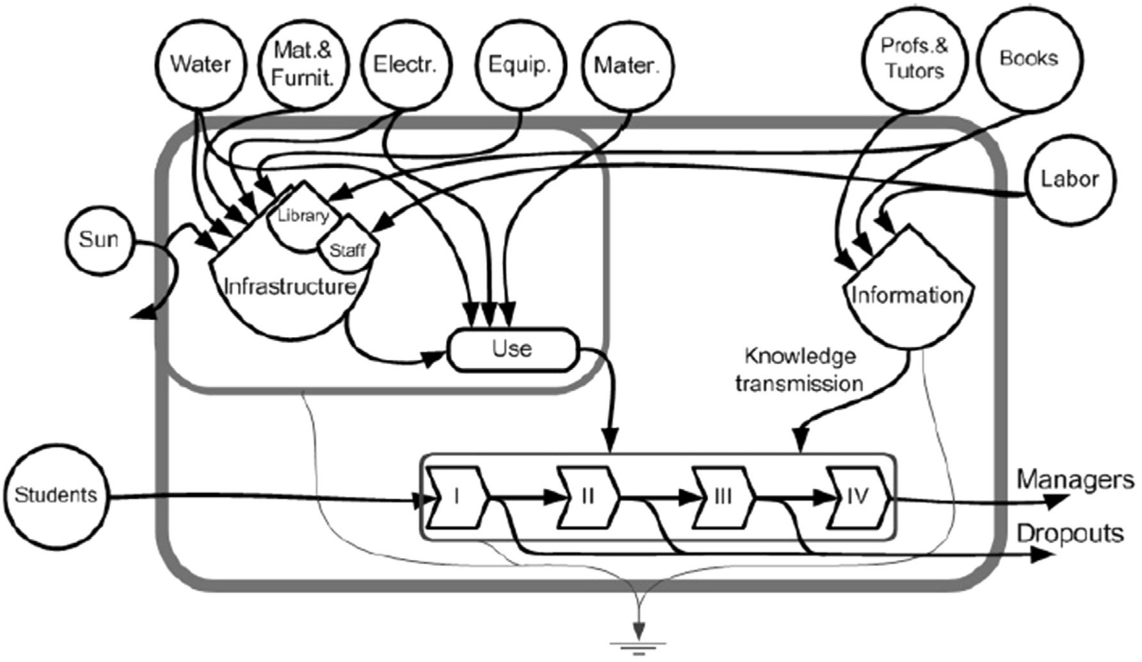

Fig. 1. Energy diagram for the course of Technical Management. Knowledge transmission may occur in classroom or via the Web.

3.1. Emergy accounting of the classroom and distance teaching courses of management technician

The energy inflows and stocked materials are represented on the system energy diagram (Fig. 1). The larger rectangle represents the system boundaries, set to the two-year duration of the course; the smaller rectangle refers to the facilities needed to run both courses. Facilities construction and set up is represented by the larger stock symbol. Entries during this phase are building materials, furniture, electrical and electronic equipment, books and labor. Information from teachers and books is considered as an energy memory, as it circulates in the world and is time-persistent. The required information to form a management technician thus comes from a stock constantly fed with teachers' instructions and information from books and transmitted to students throughout the two-year term. Infrastructure items and energy, and information flows contribute with the formation of a management technician. Students will absorb portions of formative information, while interacting with those items. A dropout's emergy will have increased proportionally to the time spent until abandonment. System outputs are management technicians and dropouts.

Tables 1 and 2 describe the inflows related to the construction of and operation of the classroom system and the distance learning system. For an easier visualization and comparison of the emergy contribution from each input to both systems in their respective calculation phases, the farthest right-side column was inserted in the table, with the corresponding percentage values for every input. The UEV's for items 24, 25, and 27 (see Tables 1 and 2) were specifically calculated for this work, using the latest calculated value of the emergy supporting Brazil (Demétrio, 2011), and data from the 2012 Brazilian census. Results show that, for the classroom system, information flows contribute with 32% of the total emergy, 85% of which contributed by the 34 students' information load accumulated until high-school completion. The largest emergy contributions to the infrastructure come from concrete and diesel consumption. Contribution from concrete to the distance learning system is the highest, at 38% of the total infrastructure (building + usage phases), followed by computers, and labor. Electricity consumption in the distance teaching system is over two times the amount consumed in the classroom system. That corresponds to 9% of its total infrastructure emergy. Contribution from the information flows to overall distance teaching system emergy amounts to 23%.

Emergy per student is 4.08 × 10^{15}seJ/2yrs for the classroom unit, and 6.02 × 10^{15}seJ/2yrs for the distance learning unit. The discrepancy is due to the differences in infrastructural costs, in terms of natural resources, and the relatively similar current number of attending students in each system; the high UEV of a computer unit explains why the infrastructure required for a distance-learning course, with twenty-five computer units and a server, nearly equals the entire emergy supporting the classroom course system. The number of attending students in the distance-learning course is 26% higher, each one using his/her own computer, which was accounted for in the “Access to Information” phase. Computers used by the classroom course students for homework are not accounted for, since their use is not

Table 1
Emergy accounting of the classroom technical course of Management.

Item	Descripton	Unit	Quantity	UEV (seJ/unit)	Emergy (seJ/*2 years*)	% (seJ/seJ)
Building Construction						
1	Concrete	g	1.30×10^{7}	2.59×10^{9}	3.36×10^{16}	64
2	Steel	g	4.03×10^{5}	6.93×10^{9}	2.79×10^{15}	5
3	Wood	g	1.94×10^{4}	1.48×10^{9}	2.87×10^{13}	<1
4	Plastic	g	4.42×10^{2}	9.83×10^{9}	4.34×10^{12}	<1
5	Iron	g	3.42×10^{4}	4.15×10^{9}	1.42×10^{14}	<1
6	Ceramics	g	2.69×10^{5}	3.06×10^{9}	8.23×10^{14}	2
7	Glass (windows and doors)	g	1.34×10^{4}	3.63×10^{9}	4.86×10^{13}	<1
8	Glass (lamp bulbs)	g	3.52×10^{2}	3.63×10^{9}	1.28×10^{12}	<1
9	Labor	J	2.17×10^{9}	4.30×10^{6}	9.33×10^{15}	18
10	Computer	g	3.34×10^{3}	1.60×10^{12}	5.34×10^{15}	10
12	Fan	g	2.88×10^{3}	4.10×10^{9}	1.18×10^{13}	<1
13	Book (library stock)	J	1.23×10^{5}	3.45×10^{9}	4.24×10^{14}	1
	Subtotal				**5.26×10^{16}**	**100**
Building Usage						
14	Sunlight	J	5.25×10^{9}	1.00×10^{0}	5.25×10^{9}	<1
15	Water (from well)	m^3	9.52×10^{1}	7.75×10^{11}	7.38×10^{13}	1
16	Electricity	J	1.17×10^{10}	2.77×10^{5}	3.25×10^{15}	27
17	Paper (office)	g	1.29×10^{5}	2.38×10^{9}	3.07×10^{14}	3
18	Paper (towel and toilette)	g	4.23×10^{4}	2.38×10^{9}	1.01×10^{14}	1
19	Plastic (cups)	g	1.94×10^{4}	5.76×10^{9}	1.12×10^{14}	1
20	Workbooks	J	2.34×10^{6}	3.45×10^{9}	8.07×10^{15}	68
	Subtotal				**1.19×10^{16}**	**100**
Access to information						
21	Bus	g	1.67×10^{6}	4.15×10^{9}	6.92×10^{15}	23
22	Diesel oil	J	1.89×10^{11}	1.13×10^{5}	2.13×10^{16}	71
23	Labor (bus driver)	J	4.12×10^{8}	4.30×10^{6}	1.77×10^{15}	6
	Subtotal				**3.00×10^{16}**	**100**
Information*						
24	Information teacher	J	1.48×10^{7}	7.30×10^{7}	1.08×10^{15}	2
25	Trainee supervisor		5.00×10^{6}	7.30×10^{7}	3.65×10^{14}	1
26	Books	J	2.22×10^{8}	2.24×10^{7}	4.97×10^{15}	11
27	Information brought in by student	J	1.37×10^{9}	2.76×10^{7}	3.77×10^{16}	85
	Subtotal				**4.41×10^{16}**	**100**
	Total Emergy				**1.39×10^{17}**	

* Information refers to the emergy required to maintain the teaching staff.
The UEV values comply with the 15.83 × 10^{24} seJ/year biosphere baseline.
See Table S3 x for UEV references.

Table 2
Emergy accounting of the Distance Learning version.

Item	Descripton	Unit	Quantity	UEV (seJ/unit)	Emergy (seJ/2 *years*)	% (seJ/seJ)
Building construction						
1	Concrete	g	2.03×10^{7}	2.59×10^{9}	5.25×10^{16}	44
2	Steel	g	6.30×10^{5}	6.93×10^{9}	4.37×10^{15}	4
3	Wood	g	4.73×10^{4}	1.48×10^{9}	7.00×10^{13}	<1
4	Plastic	g	4.54×10^{3}	9.83×10^{9}	4.46×10^{13}	<1
5	Iron	g	6.85×10^{4}	4.15×10^{9}	2.84×10^{14}	<1
6	Ceramics	g	3.77×10^{5}	3.06×10^{9}	1.15×10^{15}	1
7	Glass (windows)	g	4.64×10^{3}	3.63×10^{9}	1.68×10^{13}	<1
8	Glass (lamp bulbs)	g	2.40×10^{2}	3.63×10^{9}	8.71×10^{11}	<1
9	Labor	J	3.01×10^{9}	4.30×10^{6}	1.29×10^{16}	11
10	Computer	g	2.89×10^{4}	1.60×10^{12}	4.63×10^{16}	39
12	Fan	g	2.88×10^{3}	4.10×10^{9}	1.18×10^{13}	<1
13	Book (library stock)	J	1.23×10^{5}	3.45×10^{9}	4.24×10^{14}	<1
	Subtotal				$\mathbf{1.18 \times 10^{17}}$	**100**
Building Usage						
14	Sun	J	5.25×10^{9}	1	5.25×10^{9}	<1
15	Water (from well)	m^3	2.10×10^{2}	7.75×10^{11}	1.63×10^{14}	1
16	Electricity	J	2.86×10^{10}	2.77×10^{5}	7.92×10^{15}	42
17	Paper (office)	g	2.80×10^{3}	2.38×10^{9}	6.66×10^{12}	<1
18	Paper (towel and toilette)	g	2.70×10^{3}	2.38×10^{9}	6.43×10^{12}	<1
19	Plastic (cups)	g	3.70×10^{3}	5.76×10^{9}	2.13×10^{13}	<1
20	Workbooks	J	3.12×10^{6}	3.45×10^{9}	1.08×10^{16}	57
	Subtotal				$\mathbf{1.89 \times 10^{16}}$	**100**
Access to information						
21	Computer (students' units)	g	3.11×10^{4}	1.60×10^{12}	4.98×10^{16}	79
22	Electricity	J	4.61×10^{10}	2.77×10^{5}	1.28×10^{16}	20
23	Labor (VLE supervisor)	J	2.01×10^{8}	4.30×10^{6}	8.64×10^{14}	1
	Subtotal				$\mathbf{6.34 \times 10^{16}}$	**100**
Information*						
24	Information Teacher	J	1.49×10^{7}	7.30×10^{7}	1.09×10^{15}	2
25	Information Tutor	J	3.01×10^{7}	7.30×10^{7}	2.20×10^{15}	4
	Trainee supervisor		1.00×10^{7}	7.30×10^{7}	7.30×10^{14}	1
26	Books	J	2.96×10^{8}	2.24×10^{7}	6.63×10^{15}	11
27	Information brought in by students	J	1.75×10^{9}	2.76×10^{7}	4.83×10^{16}	82
	Subtotal				$\mathbf{5.89 \times 10^{16}}$	**100**
	Total Emergy				$\mathbf{2.59 \times 10^{17}}$	

* Information refers to the emergy required to maintain the teaching staff.
The UEV values comply with the 15.83×10^{24} seJ/year biosphere baseline.
See Table S3 x for UEV references.

indispensable, nor is it mandatorily required.

Aiming at a more detailed analysis of the contribution from the inputs to each system, a direct comparison was made between the results for each specific accounting phase in both systems, as follows: (i) infrastructure construction, (ii) usage of infrastructure, (iii) students' access to information, and (iv) information flows. Fig. 2 summarizes the results obtained from the comparison, evidencing the advantage of classroom system over the distance teaching system, in terms of environmental cost. Total emergy invested in facilities indicates the necessary investment in natural resources to create the environment where the students remain involved in learning/training activities for two years. Considering the same number of students in both courses, the construction of the Distance Teaching Center would require over 100% more emergy than the amount required to build the facilities for the classroom course, due mainly to the number of computers.

Energy and material inputs feeding the systems, such as water, paper and plastic are consumed in smaller quantities at the DTC than at the classroom unit, since there is less circulation of staff and students within the DTC facilities (Fig. 2). The virtual system is computer-dependent; therefore, 136% more electricity is consumed in the DTC than in the classroom unit. Books enter both systems as printed copies, one for each one of nineteen subjects per student. Altogether, the DTC construction and use require 112% more emergy, in comparison with the classroom unit.

The forms of access to both learning environments can be taken into consideration when calculating the total systems emergy, since the emergy required for the access can significantly influence the final results. The inclusion of a bus, diesel oil consumption and one driver's labor for two years in the calculations, causes the emergy of the physical classroom unit infrastructure to increase by 47%, whereas the students' own computers, electricity consumption, and the work of a VLE manager increases the overall DTC infrastructure cost by 50% (Fig. 2). The emergy of computers is approximately six times higher than the emergy of the bus; diesel consumption emergy is 66% higher than electricity consumption emergy; the bus driver will have expended two times the amount of metabolic energy expended by the VLE supervisor, by the end of two years. As a result, the emergy required to access and interact in the virtual classroom using computers for approximately 2 h a day is 110% higher than the emergy required to access the physical classroom and return home by bus, at the end of every school night.

Despite the slightly higher amount of information circulating within the virtual system, due to the additional work done by tutors, the sum of all information flows in both systems is practically identical.

3.2. Analysis of the use and underuse of the available resources considering teaching staff attendance potential

An assessment was carried out, by means of scenarios, of the actual current use and underuse rate of the infrastructural, material and human labor resources in both systems through the two-year operation term. Scenarios based on the maximum service

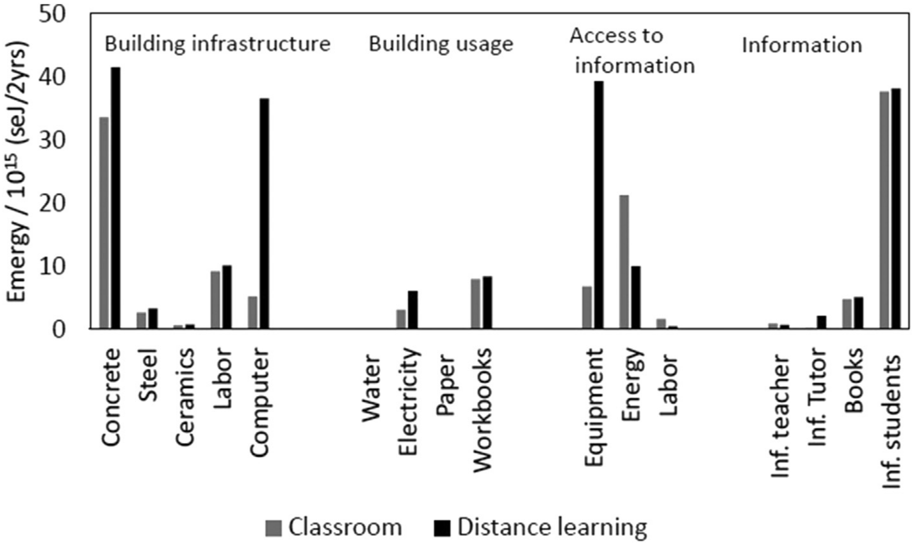

Fig. 2. Comparison of resource and energy inputs of the classroom unit and the DTC unit. Calculations assume the same number of students in each course.

capacity of the teaching staff of both systems were also built and compared.

With 34 out of 40 seats occupied, the classroom unit operates at 15% below full capacity, hence the underuse of structural and human resources and waste of electricity and fuel. The DTC is 16% below full capacity, with 43 of its 50 seats occupied, and the occurring underuse is that of teachers and tutors' service capacity. Hypothetical accountings were performed for the distance teaching course solely for comparison purposes, since an increase in the number of students would not imply expansion of DTC facilities. See Tables S1 and S2 for calculation results.

From a managerial point of view, percentage variations in investments can closely relate to cost-effectiveness. The emergy-per-student ratio is a relevant indicator in that sense, as it, too, can be an indication of how far or close to the original project an educational system is operating. Information flows circulating within the systems can be perceived by a manager as the most relevant benefit fared from the investment made in infrastructure.

Table 3 highlights percentage variations in every accounting phase, as verified in the simulations. The farthest right column expresses the amount of idle or wasted emergy from the total invested. The largest relative percentage variations observed for both systems are for the flows of information, which, in the case of the distance learning system, are followed closely by the variations in percentage for the access to the information, since one extra computer either enters the system with every new student or leaves the system along with every dropout.

Teaching staff's maximum attending capacity scenarios for both systems were based on the classroom unit staff's capacity, since the distance learning teachers' workload is an assumption (Table 3). Twenty percent of the full service potential of the teacher staff is used when attending 34, 30 or 40 students (Table S1). A scenario with five groups of 40 students using all the available time in the unit, shows the total physical unit system emergy increasing by 250%. An analogous scenario of the virtual system with five 50-student groups was created. Few variations in the contribution percentages from items are observed therein, except for 400% more workbooks entering the system, resulting in an emergy contribution 100% higher than the emergy of all the concrete used to build the unit. As for the cost to access information, in a comparison with referential Table S1, the emergy required to access the VLE would be 371% higher, a figure boosted up by the inclusion of 200 extra students' computers, consuming 277% more electricity.

3.3. Managerial decision making based on the emergy required, per accounting phase

As a robust method, Emergy Accounting may be considered as a proper tool to build studies on resource use, since its unique feature of allowing distinct forms of energy, including labor, to be accounted for in the same accounting table, makes it very practical to compare the amount and/or quality of required inputs in a given system, or to make comparisons among different systems.

The results of the emergy accounting for both systems were used to build trend-line charts from which important resource use-related facts could be inferred. Besides graphically displaying the

Table 3
Percentage variations of required emergy as a function of minimum and maximum number of students attending each course and maximum teachers' staff attending capacity.

Course mode	Number of Students	Infrastructure Δ%	Access to information Δ%	Information[b] Δ%	Emergy per student Δ%	Infrastructure underuse Δ%
Classroom	30	−7	–	−24	+17	12
	34	−5	–	−14	+7	7
	40[a]	Reference values				
	200	+116	+400	−391	+27	
Distance learning	38	−2	−22	−23	+15	12
	43	−1	−12	−13	+8	7
	50[a]	Reference values				
	250	+36	+367	+391	−8	

[a] Reference values refer to physical dimensions of classrooms (40 students) and specifications from the SETEC (50 students). Calculations available on Tables S1 and S2.
[b] Information refers to the emergy requires to maintain the teaching staff.

status of both systems, the trend lines can help a manager clearly visualize/project the expansion of one or more systems.

Fig. 3 displays direct comparisons between the courses. From the point of maximum current teacher staff capacity onwards, the emergy required to set a new complete equivalent system was considered.

The trend-line charts presented above depict the hypothetical increase in use of environmental resources in each one of the four accounting phases, in function of an increase in the number of enrolled students. The 200-student intervals refer to every new iteration of the classroom system, in function of the teaching staff's maximum attending capacity. As shown in Fig. 3 (A), the initial difference in the cost of the necessary infrastructure to accommodate 40 classroom-system students and 50 distance-teaching students gradually decreases, until the 300- student mark is reached. At that point, the trend lines cross and distance teaching infrastructure switches from initially requiring 120% more emergy, to gradually becoming more advantageous, since an increase in number of classroom-student groups will necessarily imply increasing the physical infrastructure. As for the usage of the structures, the costs in emergy are directly proportional to the number of students as on Fig. 3B, on which the trend shift at about 100 students is due, mainly, to the increase in the consumption of water, paper and electricity at the classroom unit facilities. Accessing information (Fig. 3C) in the classroom system is more environmentally advantageous. The emergy increments in this sector occur every time the number of the traditional classroom course students increases by a multiple of 50, which corresponds to the bus passenger-carrying capacity, consequently increasing fuel consumption and bus driver services. Emergy investment at each increment equals 3.00×10^{16}seJ/2yrs. Unlike buses, computers are items for individual use, in this context. Their UEV is higher than the UEV of a bus. Moreover, the emergy required to access the virtual classroom progresses linearly with the addition of one personal computer kit per newly enrolled distance-teaching student. Information flows figure is sensitive to the number of students in a system, as one of those flows is the sum of the contributions from the information brought into the system by every student, and another one is the information extracted from books. As for the information transmitted by the teachers, to each increment of 200 students in the classroom system, the corresponding information emergy will increase with a new group of teachers entering it (Fig. 3D). In the case of the distance teaching system, since alterations in the number of teachers do not occur, the emergy of the information transmitted by teachers will remain steady. However, for every 38 to 50-student group added to the system, the information transmitted by three extra tutors will also be added. The final emergy of both modes is definitively influenced by the high UEV's of information flows.

As previously presented and discussed, the results of this study show that less emergy is required to build a complete 40-student classroom system (Fig. 4A), than to build a DTC to host one 50-student group. The difference in cost gradually decreases until the 300-student mark is reached, and a trend shift occurs. Similarly to all other results obtained herein, this one derives from a perspective that considers the total emergy of each system as a whole. The next scenario, however, was built upon a simple notion of responsibility that may reflect a manager's perception concerning costs, both the financial and the implicit environmental ones, since in the distance learning mode accounting, it could be considered that students share the costs by using their own home-computers and electricity to access information. Therefore, from a purely managerial perspective, if such inputs, which are actually not financially sponsored by the institution, were not to be considered in the budget preview, the classroom system would still be more advantageous, initially; however, the trend line would cross close to the 100-student mark (Fig. 4B). From that point onwards, a distance teaching system would assume the advantage, since:

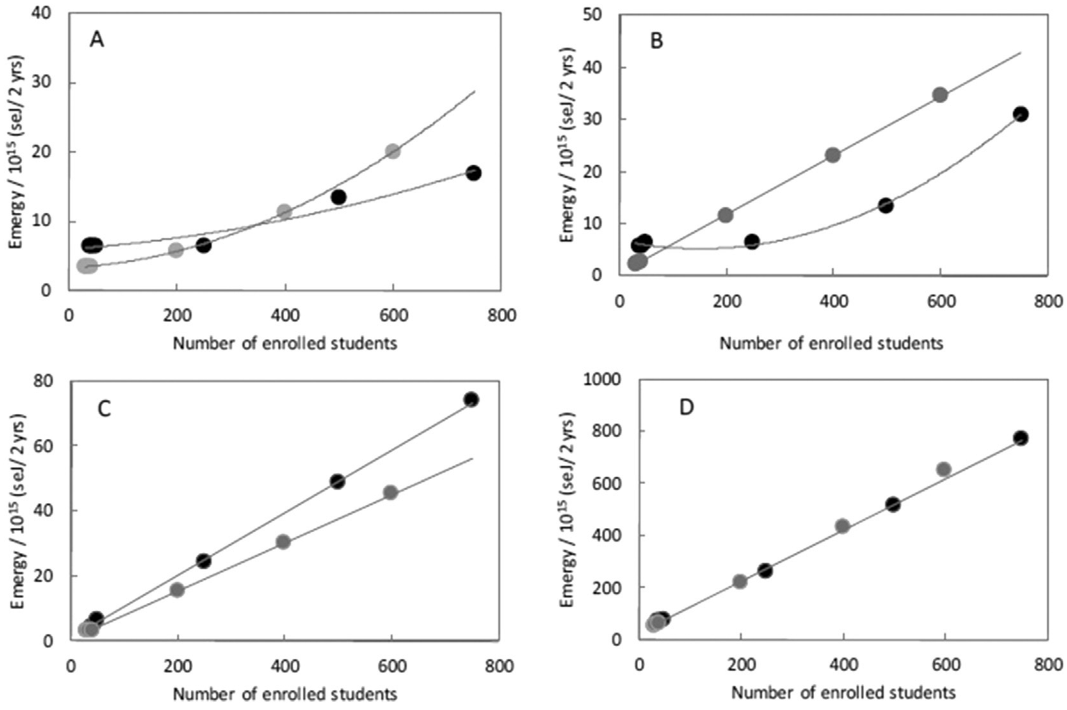

Fig. 3. Emergy demanded as a function of the expansion required to attend larger groups of students for (A) physical structures; (B) buildings usage; (C) access of the students into the learning environment; and (D) the increase in number of teachers, tutors, books. (●) Classroom and (●) Distance learning.

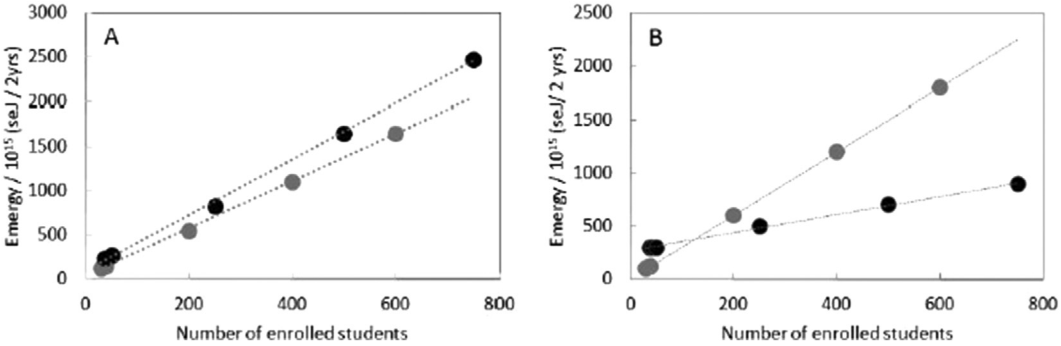

Fig. 4. Total emergy invested (A) and emergy invested exclusively by the educational institution (B) in each system as a function of number of enrolled students. (●) Classroom and (●) Distance learning.

a no expansion of the physical facilities of the DTC would be required in function of the number of students in the distance teaching system;

b based on the current classroom unit configuration as for facilities dimensions, investing in one new similarly equipped classroom would be necessary to accommodate every extra 80 students, and a new set of sanitary facilities would be required for every 150 extra students.

These results are indicative of the allocation of environmental resources backing an institutional decision favoring the availability of these courses. From a managerial viewpoint, however, the amount of information flows in a system may be perceived as a reward for the investment made, since, except for the energy generated by the labor of teachers and tutors – professionals hired and paid by the institution-, the flows accounted for the access to information do not result from items financially backed by the institution. Therefore, an environmentally aware decision upon the offer of either modality, might disregard the items the institution is not financially responsible for.

4. Conclusions

This study presents a comparison of the cost, in natural resources, to implement and run a classroom and a distance teaching course of Technical Management at IFSULDEMINAS, using emergy accounting. The results obtained for the building construction and usage phases are useful, from a managerial point of view, as it provides a different approach as for the use of natural resources when building physical structures to be used for educational purposes, where flows of information could be considered as the end purpose behind all the planning, budget allocation, engineering, and construction, in a “the more, the better” basis, allowing for cost-effectiveness analyses. The inclusion, in this analysis, of an assessment of the costs of accessing the educational environment, however, can open a school manager's eyes to the environmental implications resulting from the decision-making involving an education-related aspect he/she is usually unaware of/not concerned with.

A viable procedure has been established by this case study, which may also be used to assess and monitor actions concerning the greening of existent campuses' facilities. In short, the procedure presented in this article covers four dimensions of decision-making: (i) which course-mode to choose depending on the local demand, (ii) allows to evaluate the under usage of facilities and teaching staff, (iii) helps to decide on the best access to information, which depends on local conditions; and (iv) allows monitoring changes within courses considering environmental costs. By using emergy analysis, this procedure enables for the assessment/comparison/selection of course-modality-to-be-adopted from the availability of infrastructure or resources to be invested in infrastructure, the number of seats to be offered, based on the analysis of demand and available labor force, providing school managers and/or decision makers with a wide view beyond the financial panorama, by evidencing nature's contribution and impacts suffered in favor of human education.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2017.06.189.

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