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Post-Graduation Program in Production Engineering

THE BRAZILIAN EDUCATION SYSTEM AND THE PRODUCTION OF HUMAN CAPITAL: AN EMERGY ANALYSIS

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Dissertation presented to the Post-Graduation Program in Production Engineering of Universidade Paulista – UNIP to obtain the title of Doctor of Production Engineering.

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Guidance: Prof. Dr. Cecília Maria Villas Bôas de Almeida

Concentration Area: Sustainability in Production Systems

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Research Project: Energetic-environmental assessment of production systems using the systemic approach

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DEDICATION

This work is dedicated to the memory of my father Hugo, my mother Gilda, and my brother Sérgio Wagner, for all the principles of honesty and decency I was taught. It is also dedicated to my wife Vera, and my daughter Isabella, for the support and understanding during the time I found myself in candid pursuit of intellectual, professional, and academic growth.

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RESUMO

O desempenho econômico de uma nação é impulsionado, principalmente, por uma combinação de recursos disponíveis, infraestrutura e a qualificação de seus trabalhadores, portanto, a educação desempenha um papel fundamental no fornecimento de trabalhadores qualificados para a força de trabalho. O sistema educacional brasileiro envolve, atualmente, ações diretas de cerca de sessenta milhões de pessoas, entre estudantes, professores e pessoal técnico/administrativo/de manutenção. A educação básica é conduzida, principalmente, em escolas públicas municipais e em escolas particulares, seguidas das escolas públicas estaduais e federais em todo o país, totalizando cerca de 186.000 unidades atualmente em operação. A ação do sistema educacional na produção do capital humano que alimenta a força de trabalho nacional contribui para que o PIB brasileiro, segundo o Banco Mundial, esteja entre os dez maiores do mundo, enquanto o IBGE afirma que, para cada R$ 1 investido em educação, ocorre um retorno de R$ 1,85 para o PIB. Neste trabalho, o papel do sistema educacional brasileiro no fornecimento de trabalhadores que compõem mais de 90% da força de trabalho nacional é analisado sob a perspectiva da Síntese em Emergia. Para tal, foi realizada a contabilidade em emergia do sistema educacional em uma série histórica, compreendendo os anos de 2002 a 2017, cobrindo um ciclo completo de educação, desde a primeira série do ensino fundamental ao último ano de um curso superior. A emergia demandada para formar alunos/trabalhadores em três níveis de educação, assim como a emergia investida por aluno, foi calculada. Este procedimento também permitiu a avaliação da emergia despendida por trabalhadores de diferentes níveis de conhecimento e experiência ao longo de suas carreiras, como uma medida da retribuição pela emergia investida em sua formação. Os cálculos se baseiam no cenário real, que é uma mescla de ensino presencial e ensino a distância. Um cálculo sob a hipótese de uma migração completa para o ensino a distância também foi realizado, para fins de comparações. De acordo com os resultados, a emergia do trabalho despendida em um ano por um trabalhador de nível fundamental, um de nível médio e um de nível superior equivale a, respectivamente, 2,8, 1,6, e 1,4 vezes a emergia total investida em toda a sua formação, o que atesta que a emergia investida na formação de trabalhadores pode ser rapidamente ressarcida por meio da emergia do trabalho executado. Adicionalmente, a emergia requerida pelo sistema correspondeu a 6% do orçamento nacional de emergia em 2002, gradualmente diminuindo para menos de 2% em 2017 e a contribuição em emergia da força de trabalho em 2017 correspondeu a 38% do orçamento nacional de emergia para aquele mesmo ano.

Palavras-chave: emergia; ensino a distância; ensino presencial; capital humano

ABSTRACT

A nation’s economic performance is mainly driven by a combination of available resources, infrastructure, and the qualification level of its laborers; therefore, education plays a fundamental role in providing the workforce with qualified, skilled workers. The Brazilian education system currently involves direct actions from approximately sixty million people, among students, teachers, and administrative/technical/maintenance staff. Basic education is currently carried out mainly in public municipal and private schools, followed by state and federal public institutions nationwide, totaling about 186,000 units currently in operation. The education system’s action in producing human capital to feed the national workforce pushes the Brazilian GDP, according to the World Bank, into the group of the world`s ten largest, while the IBGE states that for every real invested in education, there is a R$ 1.85 reward for the GDP. In this work, the Brazilian education system’s role in providing the workers that compose over 90% of the national workforce is analyzed under the emergy synthesis perspective. For this purpose, the emergy accounting of the education system throughout a timeline spanning from the year 2002 to 2017, covering a full education cycle, from the first grade of the elementary (primary) school to the last year of a graduation program was carried out. The emergy demanded to support the full education cycle, the emergy required to form groups of workers in three levels of education, as well as the emergy invested per individual was calculated. This procedure also allowed for the assessment of the emergy dispended by laborers of different levels of knowledge and experience throughout their careers, as a measure of retribution for the emergy invested in their formation. The calculations are based on the actual scenario, which is a mix of in-class and distance teaching. A calculation under the hypothesis of a full migration to distance teaching was also performed, for comparisons. According to the results, the emergy of the work dispended in one year by a worker with primary-level education, one with secondary-level education, and one with a graduation-level education is, respectively, 2.8, 1.6, and 1.4 times the total emergy invested in their formation, which attests that the emergy invested in formation of workers can rapidly pay back. Additionally, the emergy required to support the education system corresponded to 6% of the national emergy budget figure in 2002, gradually descending to less than 2% in 2017, and the emergy contribution from the workforce in 2017 corresponds to 38% of the national emergy budget figure for that same year.

Keywords: Emergy, distance teaching, classroom course, human capital

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABED	*Associação Brasileira de Ensino a Distância* (Brazilian Distance Teaching Association)
CNE	*Conselho Nacional de Educação* (National Education Councyl)
DT	Distance Teaching
DTC	Distance Teaching Center
EPS	Emergy per student ratio
ETEC BRASIL	*Programa Escola Técnica Aberta do Brasil* (Open Technical School Program of Brazil)
GDP	Gross Domestic Product
IBGE	*Instituto Brasileiro de Geografia e Estatística* (Brazilian Institute of Geography and Statistics)
INEP	*Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira* (National Institute of Education-related Studies and Research Anísio Teixeira)
IRI	Information-related inputs
IT	Information technology
PC	Personal computer
SEB	Secretaria de Educação Básica (Basic Education Secretariat)
Sej	Solar energy joules
VLE	Virtual Learning Environment
UEV	Unit Emergy Value

SUMMARY

1. INTRODUCTION

Classical studies in economics classify land, capital, and labor as the fundamental resources required for the production of goods and services. Controversy was launched when sharp-eyed observers began to realize that economic success stories had been taking place in nations where those physical infrastructural assets were all except abundant. At that point, one other factor had been identified as crucial to the quality and profitability of the production process: the quality of a nation`s human resources.

The economy of nations is, in fact, driven by the systematically combined actions performed by their labor force in their production systems to produce goods and services.

The quality of performance, therefore, is intrinsically linked to the quality of human capital. As first mentioned by Smith (1776), the notion that an individual’s or corporation’s economic success relies on their attitude, skills, and knowledge applied to production of goods and services has long been recognized, theorized, and established as the basic purpose of formal education worldwide. That said, the formation of human capital receives proper attention in most powerful nations.

The amount of income from GDP invested in the national education system annually is around 6% (Agência Brasil, 2018). Under this budget, the system currently involves direct actions from about sixty million people, among students, teachers, and administrative/technical/maintenance staff. Basic education is carried out mainly in municipal public, and private schools, followed by state and federal public institutions spread nationwide, totaling about 186,000 institutions currently in operation, as opposed to 203,000 in 2006. A fact worth of notice is that, despite governmental plans to establish and promote the specific Education for the Countryside, as noted by Vendramini (2007), the IBGE reports for the last decade reveal the gradual extinction of numerous rural school units. Meanwhile, ABED data covering the same period evidence that the search for formal education via distance teaching, especially in the secondary level vocational learning and higher education, finds itself in an ascending line, as discussed by Giolo (2008), albeit not in the same proportion.

Recent numbers show that ninety percent of basic school graduates find themselves joining the labor force, while others will opt to pursue specific further qualification by attending higher education programs. Less than one percent of the nearly sixty million students, however, were attending a post-graduation program in 2018 (MEC, 2018).

In times of resources depletion worldwide, to analyze the investment in natural resources to maintain systems operational as well as to seek for the best cost-benefit ratio for their outputs is a valid and necessary measure. More so when taken into consideration that the output of a system such as the Brazilian education system is supposed to play a role of huge importance in the country's economy.

Under the notion that different aspects of a nation's economic health can be measured by using different tools, paradigms, and indicators, an environmental accounting using the emergy synthesis presents itself as an alternative, as it allows for a broad analysis, under the environmental perspective, including resources and services. In this sense, the idea behind this work is to use the Emergy Synthesis (see item 4.3) method to analyze the investment in resources to support the national education system, and the system's output as members of the national workforce with different levels of knowledge, and their contribution to the national economy. In the quest to understand this cost-effectiveness relationship, the research questions behind all the effort put in this work are "how much invested emergy does the Brazilian education system require to form a worker?", and "how long does it take an educated worker to pay it back with work?" Emergy synthesis was used to find the answers to these questions, by analyzing the amount of resources used to form workforce members and by drawing new statistic data and simulating scenarios that show the work potential of the active workforce as a result of the investment, while comparing it to the actual scenario.

2. OBJECTIVES

2.1. General objective

The main goal of this work is to perform the emergy accounting of a full education cycle of the Brazilian education system to obtain indicators related to the emergy cost of human capital production and the rewards brought to the laborforce and the economy by workers formed by the system during the cycle.

2.2. Specific objectives

- To calculate the emergy supporting the Brazilian education system through the 2002-to-2017 timeline;
- to calculate the emergy cost to educate potential workforce members in all levels of knowledge (primary, from 2002 to 2010; secondary, from 2011 to 2013; and graduation, from 2014 to 2017);
- to simulate the cost in emergy to produce potential labor force members via distance teaching in the same interim;
- to calculate the time required for the investment in human capital formation in all three levels to pay back;
- to calculate the potential emergy of the work delivered by workers of all levels throughout their careers;
- to obtain indicators related to the emergy cost of human capital production in different levels of knowledge and its benefit to society and the economy;
- to contribute to the broadening of Emergy Synthesis applications and literature;
- to produce a document that may serve as a reference in decision-making related to investments in education.

3. LITERATURE REVIEW

To reach the targets established in this work, the literature research comprises works that approach the emergy accounting method applied to construction and maintenance of buildings, the emergy of information in education systems, and the role of education in the formation of human capital. A search for literature material connecting emergy and distance teaching was also performed. A large part of the emergy accounting of the energy inputs supporting education systems has been covered by a few authors, including Almeida et al. (2013), and Oliveira et al. (2018), while the emergy of information has been explored by other authors, and has been the subject of a number of proposals as to approach. Moreover, since this work attempts to connect formal education as a preparation for the inclusion of the graduated student into the workforce, a search was carried out for human capital-related literature, with the purpose of providing with some historical background on the human capital theory.

3.1. Emergy analyses of education systems

3.1.1. Buildings construction and maintenance

An emergy synthesis of a school unit considers the emergy required to build, operate and maintain the physical facilities, as well as the emergy supporting the flows of information generated by the interaction among students, teachers, materials, and the infrastructure.

The body of works on emergy of schools, universities and education systems include the pioneering efforts of Odum (1999b), who performed the emergy accounting of the University of Florida, envisaging the proposal of an environmental policy for the institution, through the inclusion of environmental education essentials for all students, and a Graduate Curriculum for environmental professionals.

As for the emergy required to construct and maintain buildings, some of the pioneering works in this sense are referential. For example, Buranakarn (1998) evaluated the recycling and reuse of construction materials, using the emergy analysis. Later, Brown and Buranakarn (2003) assessed the emergy of the life cycle and the emergy of disposal and recycling of the most common construction materials. The resulting emergy values calculated for these materials have been used in a large number of emergy analyses involving construction of buildings.

The relevance of the emergy contribution from inputs related to the usage of buildings to specific purposes, i.e. the building’s operational function, is explored by different authors, including Meillaud et al. (2005) who used emergy accounting to evaluate the Solar Energy and Building Physics Laboratory (LESO) building, located on the Lausanne campus of the

Swiss Federal Institute of Technology. The authors used UEVs for construction materials that were obtained from the works of Odum (1996) and Buranakarn (1998). The authors also calculated the UEV for several building construction and maintenance inputs by summing the emergy of each input, then dividing the total emergy by the amount of produced material. The emergy of information carried by students, faculty, and staff was included in the calculations. The authors concluded that the most important input was information, followed by electricity, which is an input related to a building's operation.

A building's lifespan is considered in emergy analyses, as its contribution to the emergy accounting equals the fraction of its lifespan that corresponds to the analysis timeframe. Endorsing the variations in lifespan estimations assigned to buildings in literature, Kowalsky (2002) mentions the non-uniformity of school buildings lifespan, a notion endorsed by the fact that some buildings are projected to withstand 70 years of use, while others become obsolete in less than 40 years. Meillaud et al. (2005) assigned a 80-year lifespan to the LESO school building. On the other hand, by stating that buildings could be conceived as "thermodynamic engines", Pulselli et al. (2007), for instance, assessed an Italian residential and commercial building by separating the emergy analysis into distinct phases: i-construction – time-persistent construction materials included in the inventory as stock materials; ii-maintenance – emergy of materials used to avoid the buildings depreciation; iii- usage. The authors concluded that the annual emergy investment to maintain the building operating corresponds to approximately 30% of the annual emergy of building construction, also considering a 50-year lifespan.

Most of the works cited above are referential to later works and fundamental in setting the more updated calculation frameworks used in more recent studies, such as Almeida et al. (2013), who used emergy accounting to evaluate the inputs supporting the engineering programme at Universidade Paulista, including the facilities, and Oliveira et al. (2018), who compared an in-person, classroom-based verion, and a distance teaching DTC-based version of a vocational course of Management at the Federal Institute of Southern Minas Gerais, in Brazil. Both works also include the calculation of the emergy of constructing and maintaining school buildings, and in both, the assigned building lifespan was 50 years.

3.1.2. Computers, computer usage and electricity consumption from internet usage.

Computers and information technology are an important, if not indispensable in certain fronts, component of the education systems. Methodologies are advancing in the sense of providing students and teachers with virtual tools that enhance the teaching and learning process.

In addition, the ever-growing field of distance teaching relies completely on Information Technology (IT) and the varied current versions of a computer machine. Recognizing the importance of computers in systems empower, Di Salvo and Agostinho (2015) used a sample of ten popular computer models in a first attempt to calculate the UEV for computers. As such, the main weak points of the analysis, as pointed out by the authors, include the fact that one single reference as to computer components was used, as well as considering all inputs as non-renewable. However, the authors presented two alternative sets of calculations, one of which using computers mass as a functional unit to calculate the sej/g UEV with and without services, and the other one using a computer`s capacity power as a functional unit to calculate the sej/Flop UEV, with and without services. The authors verified that the services included, represented therein by the units market price, accounts for 90-97% of the UEV total, independently of the functional unit. Both values – with and without services- for the UEV of computer units found by these authors have been regularly used in emergy analyses, including this work.

Videoconferences, along with audio and video streaming and written material are some of the tools used in distance teaching virtual platforms. Streaming of audio and video require higher transfer speeds that vary widely, according to resolution rates of the source material and the quality of the transmitter and receiver equipment. As verified by Ong et al. (2014) while comparing the energy, carbon emissions and time costs of videoconferencing versus in-person meetings, electricity consumption by computers oscillate, depending on the task being performed by the user. These authors also calculate the consumption of a laptop computer and a desktop computer to be 40 W and 150 W, respectively, in 2014. These findings can be used as a parameter to estimate the average power consumption of older computers used in distance teaching activities, as well as those present in Brazilian schools throughout the timeline.

3.1.3. Emergy of information transfer processes

Odum (1996) refers to information as being the most important input to a large number of systems. The author emphasizes the role of DNA of seeds, and books as information carriers featuring their own form of energy to perform work in the information transfer process. As far as human knowledge is concerned, the emergy of the information flows within a system can be measured as the contribution from individuals with different levels of knowledge and experience to a system’s operation, which can be measured in joules of metabolic energy per unit time spent in the system. Odum devised a method for calculating transformity (or UEV) values based on levels of education, under which, the joule of work performed by an individual in any level of education and experience can be obtained by dividing the national emergy budget (in a given year or period) by the metabolic energy of the population in a given level of education. To illustrate, the author calculated the transformity (sej/j) of the work performed by individuals belonging to different levels of knowledge and experience in the United States in 1980, by dividing the 1980 emergy budget for the United States by the metabolic energy dispended by all the individuals pertaining to different levels of knowledge and experience at the time, based on a 2,500 kilocalorie/day, or 3.82 x 10^9 kcal/yr diet.

A number of authors, however, have used different approaches and variations when calculating the flows of information in systems, which influences the contribution from information to the total system emergy. As an example, according to the results obtained by Meillaud et al. (2003), the information inputs from high school students and undergraduates amounted to 94.6% of the total system emergy supporting the LESO Building at the Federal Institute of Technology of Switzerland campus in Lausanne. This was calculated as the time of interaction spent by students and faculty annually in the LESO environment, by multiplying the total number of student and faculty members by a 5.4-hour/day journey, times 365 days/year, multiplied by 0.7, considering 30% of the time was spent outside the building in conferences, seminars, etc.

Mai Po, in Hong Kong, China, is a 380-hectare natural resort with a high educational value. Qin et al. (2000) used emergy accounting to evalutate the Mai Po education system, as well as the investment in the education system and the emergy contribution from the resort's 17 employees, from which three are post-graduated, three are graduated, and eleven are students. The emergy contribution from the visitors' knowledge was calculated as Hong Kong's total emergy budget for 1998 divided by the number of people in each local education level, thus obtaining the emergy per individual in each level. The emergy contribution from the employees' knowledge dedicated to educational purposes was obtained by multiplying the number of employees in each education level by the corresponding national education level emergy. According to the authors, the total educational function emergy of Mai Po is the sum of the employees' knowledge emergy, which corresponds to 92% of the investment in the education system and 80% of the total education system emergy.

The process of teaching and learning consists of interaction among teachers, students, and materials. Estimates are given to the students` and teachers' emergy delivered while in interaction, according to the nature of the information carrier that the students interact with. For instance, it is estimated that the mind`s retention of written material equals 10% (Dale, 1969), which is represented by one tenth of the emergy of books in the system, whereas the teaching process varies from 1% (Odum, 1999b) to 10% of the human metabolic energy that teachers spend in interaction with students, according to different authors. This approach was used by Campbell (2007) when evaluating the emergy basis for formal education in the United States education system, under the emergy method. The analysis covered the period from 1870 to 2006. The authors divided the system into three subsystems: elementary, secondary and college. The emergy of teaching and learning was quantified as the sum of the emergy brought into the system by the students and the emergy dispended during the time spent absorbing new information every year. The emergy-per-student ratio was calculated based on the time the students spend in the school. It was assumed as reasonable that people dedicate 10% of their time to learn. Moreover, the authors state that the emergy of teaching and learning was higher than the emergy required for the education system by one order of magnitude. The authors also claim that for every solar emergy joule invested in the system, there is a 10:1 return to society. By this, the author means that the emergy of teaching and learning is one order of magnitude higher than the emergy required to support the U.S. education system. This approach was reutilized when Almeida et al. (2013) assessed the Engineering Program by using emergy accounting to assess the energy, materials flows, and information transferred to students. According to these authors, the first grade students of the Engineering Program enter the system carrying 53% of the information emergy required to become a graduate engineer, which was previously obtained from high school education. Also according to the authors, the UEV of the students' knowledge increases 7.7 times by the end of the program, as compared to the UEV of their knowledge as high school graduates. The results were compared to the results previously obtained for the Pharmacy and Business programs, which enabled for a holistic view of the system. The resulting emergy from the information flowing in the system amounts to 85% of the total system emergy. The method used by these authors when calculating the UEVs for teachers and students, however, considered calculating a specific UEV for a joule of work of a Brazilian college professor, and the specific UEV for the joule of work of a student who just egressed from high-school, whereas Odum (1996) considered diving the national emergy budget by the entire population in a given level of education when calculating those UEVs, which results in lower UEV values.

Distance teaching has become an important tool in the inclusion of citizens into the education system, with more and more adepts every year. The importance of distance teaching comes from the flexibility in terms of students' interaction with formation materials and teachers/tutors, especially for those who cannot quit their jobs and/or daily duties, or overcome the problem of physical distance between home and school, to be in-person in a school environment. In this sense, its peculiarities have been the object of studies, including accounts of savings in the in-campus use of natural resources resulting from its predominantly out-of-campus nature. Roy et al. (2008), for example, conducted an environmental audit based on data from 13 campus-based and 7 print-based distance learning higher education courses and distance/open learning methods in the UK. The results were converted into energy and CO_2 emissions per 100 hours of study. According to the results, distance learning Higher Education courses require 87% less energy, and CO_2 emissions are 85% lower than the full-time campus-based courses. Part-time campus activities reduce energy and CO_2 emissions, respectively, in comparison with campus based-courses. Energy consumption and emissions reduction from part-time use of campus result mainly from reduction in student travel and elimination of a large part of the energy required in campus utilization. The analyses presented by the authors, however, focus specifically on in-campus energy and emissions reductions, and do not consider changes in other important aspects such as staff and facilities as a result of reduced campus usage.

Oliveira et al. (2018), on the other hand, included extra-campus use of energy and CO_2 emissions in their analysis. The authors used emergy accounting to compare the use of resources to implement and operate a two-year in-class course of management to a similar course in distance teaching mode. A detailed accounting of energy and required inputs of material to operate each mode, including specific staff and facilities, was performed for four distinct phases: implementation, operation, students' access to the class environment – both physical and virtual – and the flows of information generated by the teaching-learning activities. The authors used Odum's (1999b) approach to calculate the information from teachers that is absorbed by the students (1% of the teachers' metabolic energy dispended during classes) and adopted 10% of the students' metabolic energy as representative of the previously obtained knowledge of the students' (Meillaud et al., 2005). The contribution from workbooks in information transfer was also considered. The results show that under the current configurations, the emergy required to support the infrastructure, operation, access to information and teaching and learning interactions in DT mode is 85% higher than the emergy required to support the in-class version of the course. This difference derives mainly from the use of computers to access the virtual school. The emergy of information in DT mode is 75% higher than the emergy of information in the in-class mode, due to the work performed by online tutors. However, a projected scenario including a larger number of students resulted in a trend shift, whereby the total emergy values were equal at the 300-student mark for both modes. From this point on, with more students in both modes, the DT mode becomes gradually more advantageous, as the emergy required to support DT becomes gradually lower than the emergy required to support the in-class mode. In this work, the method of UEV calculation differs from the work of other authors, in that the national emergy budget was divided by the estimated total population belonging to the education levels, resulting in lower UEV values than those in the works of Almeida et al. (2013). By this method, the emergy of teaching and learning contributed 25% of the total systems emergy, in average.

Some authors have put forward alternative approaches as to the emergy contribution of human work in production systems. For example, when analyzing a number of authors' approaches to calculating the emergy contribution of labor in systems where information is relevant, Bergquist et al. (2010) argue that said contribution is potentially overestimated or underestimated in a system, since the UEV that corresponds to one's education level is considered, in lieu of the actual necessary knowledge to accomplish a specific task. This implies presuming that, independently of the level of simplicity/complexity of the task, the work performed by a highly educated individual should be assigned a higher level UEV, i.e. an empirically-learned simple task performed by an individual who holds a PhD degree should be considered a high quality contribution, independently of the context. The authors, therefore, suggest that a more appropriate assessment of the contribution from labor should consider at least four aspects: calorie consumption, the quality and quantity of knowledge, how the knowledge was generated and obtained, i.e. transferred among individuals and the society, and the cultural context the work is applied in. The authors argue that this can be achieved by separating the stocks of information from the labor inputs in the systems diagrams (Figure 1), and subsequently connecting them to the processes in a specific manner in relation to the task.

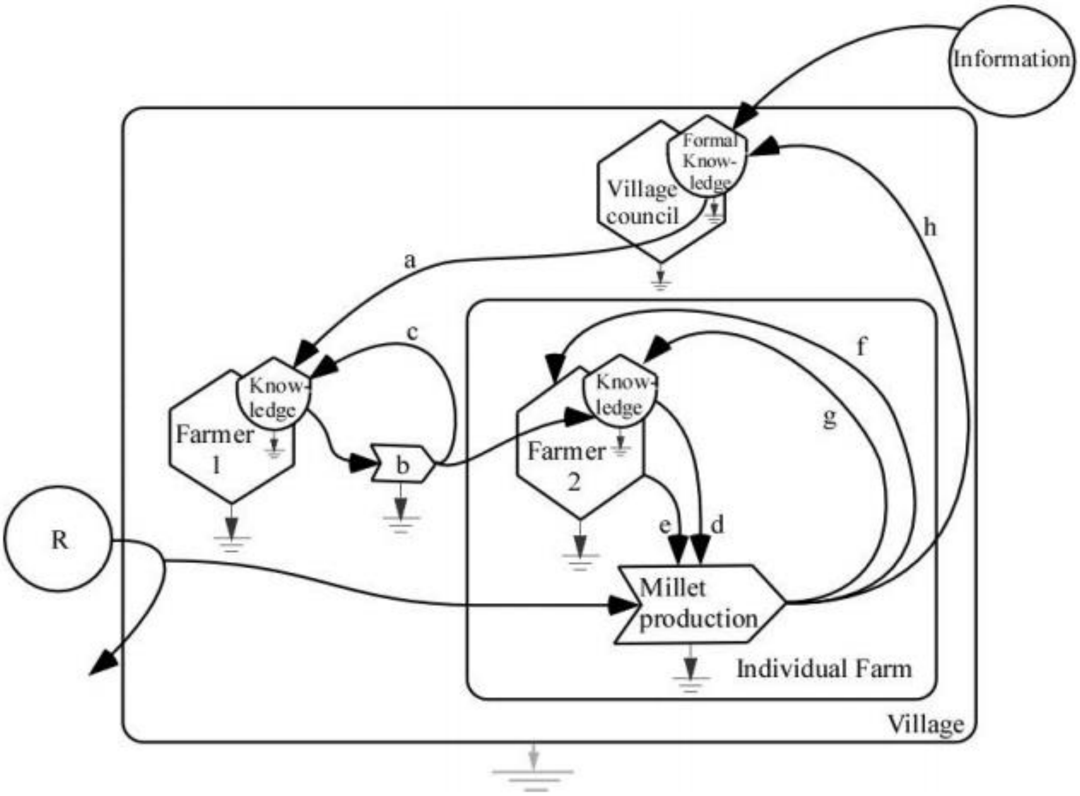


Figure 1. Knowledge flows in a millet system at village level. Source: Bergquist et al., 2010.

Simulating a system based on a hypothetical subsistence millet system, the authors used kilobytes of information as specific emergy units per unit, the equivalent of the necessary digitally stored information to maintain the millet system, according to a table from the Data Storage Calculator website. The total is, then, multiplied by a UEV based on the accumulation of external emergy entering the system for the last one thousand years, a period, according to the National Research Council (1996), equal to the time millet has been used in households.

3.1.4. The role of information carriers

The role of information carriers has received special attention from a few authors. In interaction with students, one of the most usual teachers' tools is oral information transfer. In this sense, Abel (2011) developed the Cultural Information Cycles as an analogy to Odum's (1996) Information Cycles. Abel used Odum's study of tropical forest tree species from Puerto Rico as a template. In the sequence, Abel details the first behavioral study he carried out, aiming at collecting data that was later applied to the culture-sharing dynamics in conversation cycles, using a 32-student group to analyze the conversation among Taiwanese undergraduates. According to students' notes, from the over 4,000 conversation topics that emerged during the three-week investigation, 39 became recurrent, among which only three became again recurrent. Using estimates from Abel (2011) about conversation behavior, such as the average duration of a conversation and the average number of people participating in the conversation (9 minutes and 2.5 people respectively), among other variables, the author establishes the emergy of the population involved in conversation and the energy of the information flow of the conversation carrier, then calculating the transformity of the conversation, in a contextual manner. The author thus establishes a standard procedure for the calculation of the transformity of conversation in other contexts.

The role of books as information carriers may also be considered in emergy accountings of education systems. To better understand the inclusion of books as relevant information-carrying tools, one must refer to Odum (1996), who states that information, even if it is in compact form, requires some form of energy as a carrier, and cites the DNA of seeds, the paper of books, the neuro-electrical processes of the brain, and the electromagnetic waves of radio transmission as examples. In this sense, Campbell and Cai (2007) reviewed the basis for the calculation of the emergy of books. The authors consider the energy in ten thousand copies, the emergy of paper, the emergy of publishing, the emergy of authorship- assuming 30 days of post-graduate labor at 2,500 kcal/day to to reach the transformity (sej/J) of a book. These parameters were used to calculate the UEV of books (2.24×10^7 sej/J), which was used in this work.

3.1.5. The role of education in the formation of human capital

The earliest known references to the quality of labor as a determinant factor for a nation’s economic performance come from Smith (1776), who, in his work entitled The Wealth of Nations, first mentioned the notion that the quality of human labor is as determinant in a nation’s economic performance as its available resources and infrastructure. As a result of the positive feedback to Smith’s thoughts, Mincer (1958), who is often cited as the precursor of the human capital theory, identified the existence of a relation between investments in workers formation and the distribution of personal income. As Schultz (1973) later pointed out, a number of influential economists had already mentioned the prominent role of man in modern economic development, albeit in a shy manner, due to the ethical, moral, and philosophical implications of considering man as a type of capital. The author counterpointed by widening the traditional concept of capital and shaping a new concept of investment for the modernization of economy that included human labor, which he named The Human Capital Theory, by relating an increased man’s welfare with their capacity to enlarge the array of choices before them, as a result of investing in their own professional skills. According to Kliksberg (1999), the World Bank identifies four basic capital forms: i- natural capital; ii- built capital, which refers generically to the infrastructure implemented by man; iii- human capital, which is determined by the people’s food, health, and education; and iv- the social capital, a recent discovery by the sciences of development.

Formal education prominently contributes to the formation of a nation’s potential workforce. Furthermore, constitutionally classified as one of the State’s duties in favor of its people, formal education is mostly funded by the social security receipts. 80% of all Brazilian schools are public schools (INEP, 2002-2017). The literature review on the contribution of education to a nation’s economic performance endorses the notion that education is an investment of utmost importance. In fact, Article 22 of the chapter on education in the Brazilian Federal Constitution of 1988 establishes that the aim of basic education is “to assure the students the common indispensable formation to exercise citizenship while providing them with the means to progress in work and in further studies”.

4. MATERIALS AND METHODS

4.1. Raw data sources

Most of the data required for this work is available online. However, for some specific features of the research work, obtaining accurate numeric and statistic data in order to establish calculation parameters was one relevant limitation to this work, due to the amount of data conflicts among sources. The sources and selection criteria used to obtain information allowing for the construction of the actual 2002-2017 cycle scenario are explained in the topics that follow.

4.1.1. Data on the traditional (physical) school students, teachers, and institutions, distance-teaching graduation courses and students

Statistical data on traditional schools (in-class) student enrollments, schools in operation, teachers, and courses were obtained from the INEP synopses on basic education and graduation, which is the official government-sponsored reference data source. The annual publications from 2002 to 2017 are available for download at its official website. The graduation statistics publications contain part of the data on distance teaching centers, DT courses, and students' enrollments that were used in this work.

4.1.2. Data on distance teaching students, tutors, courses, and distance-teaching centers

Data on the distance-teaching universe were partly obtained from the ABED (formerly ABEAD, ABRAEAD) annual reports, available at the official website (http://www.abed.org.br/). These reports were first published in 2004, and from that point, all issues up to 2017, whenever available, were used. Some basic statistics on DT activities were either missing or conflicting with those from INEP, since its reports rely on information provided by surveys applied to DT institutions, with a return rate from those that volunteered to respond lower than 30%. These publications were the main source of data for statistics on basic school courses via DT for this work.

4.2. Additional data sources

Statistical data used as references in calculations and creation of scenarios involving the national labor workforce and labor market, as well as complementary material on the education system and population were also obtained from a number of other official open-access databases and websites. The main ones are listed below.

a- The Ministry of Education website; (https://www.mec.gov.br).

b- *Instituto Brasileiro de Geografia Estatística* - IBGE - (Brazilian Institute of Geography and Statistics) website (https://www.ibge.gov.br/);

c- *Instituto de Pesquisa Econômica Aplicada* - IPEA (Institute of Applied Economics Research) website (http://www.ipea.gov.br);

d- The World Bank website; (https://www.worldbank.org).

e- Population Pyramid website. (https://www.populationpyramid.net/brazil/2017/).

4.3. Emergy accounting

Emergy (with an "m") is the energy of one kind previously used up to make a good or a service (Odum, 1996). By using solar energy joules (sej) as a common measure unit, Emergy accounting is an environmental accounting method that allows for the quantification and sum of inputs of different types into a system, i.e. grams (g), cubic meters (m^3), joules (J), currency ($). The result is the total emergy required to implant, operate, and sustain a production system over a period, for example, sej/year.

The first step consists of building an energy systems language diagram, which includes using specifically designed symbols. Inputs flowing into the system are placed in ascending order, from left to right, in terms of energy transformation. A generic emergy diagram is displayed in Figure 2. The second step of Emergy accounting include construction of an inventory, in which the relevant inputs are listed.

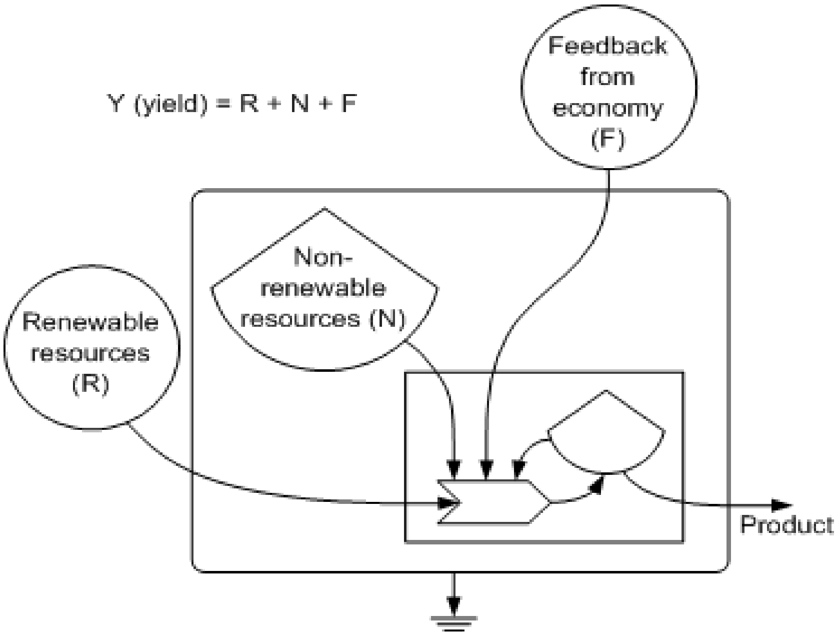


Figure 2. Energy diagram illustrating the location of inputs. Legend: (R) = renewables; (N) = non-renewable; (F) = feedback from economy; Y is the sum of the inputs.

The following step is the construction of the accounting table, where the inventory items are then described, quantified, converted and integrated to the emergy total. A generic table model is illustrated in Figure 3.

Note	Item Description	Unit	Energy flows/yr	UEV (sej/unit)	Emergy (sej/yr)
	System implementation				
1		g			
2		m3			
3		$			
	System Operation				
4		J			
5		J			
6		J			
	Total Emergy				

Figure 3. Emergy accounting table sample

The inventory comprises 17 items that were considered as most relevant, in terms of emergy contribution to the system, accordingly distributed into four accounting phases: i- campus/DTC implementation (concrete, steel, and computers); ii- campus/DTC operation (electricity, books, and staff labor); access to information (transportation to physical campi, and access to virtual learning environment); iv- teaching and learning (formative interaction among teachers, students, and books). The selection of items derives from the analyses of education system accounting works, both from other authors and self-produced (Oliveira et al, 2018), from literature. Details and considerations on the inputs enlisted are exposed as follows:

4.3.1. Items 1 (concrete) and 2 (steel)

Items 1 and 2 derive from the dimensions of the physical facilities in a school campus or a DTC. Wall, ceiling and floor thickness were drawn from Oliveira et al. (2018); considering a structure made of reinforced concrete - 97% concrete, and 3% steel. The emergy contribution in an annual emergy-based analysis corresponds to one year off an item’s lifespan. The considered lifespan for school buildings considered in this work is 50 years. The basic dimensions of both types of facility adopted in the calculations are explained in the next two sections (see calculation details for physical schools in Appendix A).

(I) Physical schools (classroom teaching mode) dimensions and materials

Estimates on dimensions of physical schools (traditional schools) used in this work are based on the description of the "functionally ideal infrastructure" for secondary schools, as described in the document from the CNE/SEB entitled *Parecer CNE/SEB Nº 08/201*, published by the Ministry of Education. This document describes the necessary infrastructure for pre-school, elementary, and high school, separately, including constructed area, room divisions with their respective dimensions, personnel, and operational material, among others. The decision to use secondary school dimensions as the general measure per institution in this work is due to the fact that these campuses feature the largest areas; furthermore, although described distinctly in the document, in practice, primary and secondary schools traditionally share the same facilities. Therefore, an assumption is made herein that all institutions accounted for do carry all levels of basic education. Table 1 contains the description of a basic school structure, as provided in the document. Calculation details can be accessed in Appendix A.1.

Table 1. Subdivisions of a functional secondary school campus.

	Building Description	**Quantity**	**Sq. Meters/item**
1-	Classrooms	15	45
2-	Directors' and staff rooms	2	30
3-	Pedagogy staff room	1	30
4-	Teachers' room	1	50
5-	Library and computer lab	1	100
6-	Students' society room	1	45
7-	Computer lab	1	50
8-	Science lab	3	50
9-	Restaurant	1	80
10-	Kitchen	1	25
11-	Indoor court	1	500
12-	Lavatories	8	20
13-	Deposit room	2	30
14-	TV/Movie room	1	50
15-	Photocopy central	1	15
	Total		2,080

Extracted from Parecer CNE/SEB 08/2010

The total quantity of concrete and steel in grams for one unit is multiplied by the number of school units in operation in a given year. The annual contribution from buildings corresponds to 1/50th part of the total amount of concrete and steel, considering their lifespan is 50 years. The numbers of operating units from 2002 to 2017 were obtained from the INEP Synopses (see Table 2).

Table 2. Number of education institutions in operation from 2002 to 2017.

Year	**Number of Basic Education Institutions in Operation**										
	Location/Administrative Jurisdiction										
	Total	**Urban**					**Rural**				
		Total	**Federal**	**State**	**Municipal**	**Private**	**Total**	**Federal**	**State**	**Municipal**	**Private**
2002	**214,188**	**106,756**	151	28,185	45,068	33,352	**107,432**	51	8,013	98,467	901
2003	**211,933**	**108,605**	157	27,887	46,465	34,096	**103,328**	49	7,891	94,431	957
2004	**210,094**	**109,737**	155	27,490	47,720	34,372	**100,357**	47	7,771	91,711	828
2005	**207,234**	**110,677**	160	27,065	48,718	34,734	**96,557**	48	6,653	89,075	781
2006	**203,973**	**111,801**	160	26,955	49,884	34,802	**92,172**	46	6,381	85,010	735
2007	**198,397**	**110,011**	189	26,761	51,093	31,968	**88,386**	46	6,353	81,361	626
2008	**199,761**	**113,184**	213	26,549	51,920	34,502	**86,577**	52	6,243	79,646	636
2009	**197,468**	**114,432**	243	26,323	52,758	35,108	**83,036**	57	6,114	76,288	577
2010	**194,939**	**115,551**	285	26,167	53,376	35,723	**79,388**	59	5,993	72,770	566
2011	**193,047**	**116,818**	383	26,121	53,982	36,332	**76,229**	68	5,983	69,627	551
2012	**192,676**	**118,564**	423	25,707	54,936	37,498	**74,112**	67	5,690	67,793	562
2013	**190,706**	**119,890**	442	25,356	55,867	38,225	**70,816**	70	5,535	64,614	597
2014	**188,673**	**121,132**	470	25,280	56,444	38,938	**67,541**	73	5,478	61,353	637
2015	**186,441**	**121,737**	552	25,262	57,217	38,706	**64,704**	84	5,525	58,470	625
2016	**186,081**	**123,032**	594	25,170	57,906	39,362	**63,049**	93	5,489	56,813	654
2017	**184,185**	**123,451**	607	25,109	58,354	39,381	**60,694**	92	5,410	54,545	647

Adapted from INEP; Statistical Synopses, 2002-2017

(II) Distance-teaching centers (DTCs) dimensions and materials

The approximate quantities of concrete and steel used in the construction of a DTC are based on the description found in Oliveira et al. (2018), where a DTC was actually measured. The decision to adopt these measures in this work are endorsed by the fact that the DTC described in the aforementioned work complies with the E-Tec Brasil program specifications, featuring a computer lab, video-room, tutors' base, coordinators' room and reception, totaling 130 sq. meters (see Appendix B for Distance Teaching Centers calculation details).

4.3.2. Item 3: computers

This item refers to computers installed in schools and DTCs for staff (08 units) and students' (31 units) use, as prescribed in the *Parecer CNE/SEB Nº 08/2010*. In the estimations made in this work, 95% of the schools were assumed to be equipped with desktop type machines, with printers in the case of those for staff use. The result derives from the approximate total gross weight of all the machines. The considered lifespan of a computer is 5 years, according to directions from the Receita Federal do Brasil (Brazil's Federal revenue department) for assets depreciation (see Appendix A1.3 and B1.2. for calculation details).

4.3.3. Item 4: electricity

This item (total electricity consumption) is the sum of the electricity annually consumed in traditional campuses and DTCs for lamps, computers, printers, and data projectors (see Appendixes A2.1 and B2.1 for calculation details).

(I) Lamps

The number of lamps in a campus is a low estimate based on the rooms dimensions. One 40W phosphorescent lamp bulb for every four square meters, in average, was considered. Lamps energy consumption considers their daily use for four hours during the night shifts, only. The number of lamps considered for a DTC derives from the work of Oliveira et al. (2018) which describes an actual DTC, in which thirty 40W lamp bulbs are used.

(II) Computers

The number of computer units in use in every campus derives from the *CNE/SEB Nº 08/2010* description, which assigns 08 units for staff use, plus 31 unit for students use. It was also assumed that 95% of schools have computers available for administration staff use and 90% have computers available for students use, due to an observable lack of proper infrastructure in rural-area schools, especially.

4.3.4. Item 5: books

The books mass was calculated based on a considered weight of 250 grams/unit, eight units per student/year. Lifespan considered for a book is 20 years (see Appendix A2.2 for calculation details).

4.3.5. Item 6: labor (staff)

In this work, the UEV per joule of work from staff member refers to labor that is not directly related to information transfer activities, as in teaching and learning activities. This variation of the UEV does not consider the worker’s education level. The decision to use this variation is due to the lack of strict regulation of staff work requirements as for professional formation. Therefore, a decision was made to use intellectual work-related UEVs exclusively to quantify the work of teachers, tutors, and students in formative interaction. Calculation details can be accessed in Appendixes A2.3 and B2.2.

(I) Traditional school technical/administrative staff labor

Total labor emergy results from the metabolic energy dispended during work hours. By assuming an individual's daily 2,500-kilocalorie consumption, the worked hours are multiplied by 120 kilocalories per hour; the total is then converted to joules. The number of staff members vary from institution to institution. Hence, the standard staff configuration dictated in *CNE/SEB Nº 08/2010* (Table 3) was adopted.

Table 3.Recommended school management staff

School Management Personnel (CNE/SEB Nº 08/2010)	
School principals	2
Secretariat	4
Maintenance and Infrastructure (primary-level employee)	4
Maintenance and Infrastructure (secondary-level employee)	4
Pedagogy coordinators	2
Librarian	2

(II) Distance teaching center staff labor

DTCs have a leaner staff structure. The model adopted in this work includes four workers, as described in the table 4. This configuration is speculative, since every distance teaching institution is set up as deemed necessary. This set up refers strictly to staff members who perform work within the DTC premises.

Table 4. DTC management personnel

School Management Personnel (Oliveira et al., 2018)	
Institution principal	1
Secretariat	2
Equipment and virtual platform manager	1

4.3.6. Items 7 and 8: Transportation, fuel

(I) Transportation

The transportation accounting refers to the emergy of the students' round trips to the physical school premises. The vehicle adopted as standard in this work is a 16-seat van. The mass of one unit is 4,000 kilograms. Since the legislation on the lifespan of public school transportation systems vary from state to state, the lifespan adopted is 12 years, based upon Law Project PL 5585/16. (see Appendixes A3.1 and A3.2 for calculation details)

(II) Diesel consumption

For the calculations, it was assumed that the number of vehicles derives from the number of students divided by the number of seats in a van. Fuel consumption is one liter of diesel every 10 kilometers; the roundtrip to and from school is 60 km. Diesel consumption was calculated in liters and converted to joules.

4.3.7. Items 9 and 10: Computers (D.T. students' units), electricity consumption from students' computers use

(I) Students' computers

Gaining access to virtual classrooms is now possible by using a variety of audio/video devices, from satellite television and computers, to smartphones and tablets, however, there are no available statistics on the percentage of device types currently used by students, nor specific UEV values for information appliances other than the computer. Thus, the average desktop-type PC (personal computer) was considered as the standard device in the calculations, since the current conception of distance teaching methodology (using IT), generally speaking, was developed when desktop computers were the only option available. The number of PC units considered equals the total number of DT students. The setup mass considered was obtained by weighing a combination of components made around 2010, which is the midpoint of the timeline established in this work (see Appendix B3.1 for calculation details).

(II) Electricity (from students' computer use)

As inferred from Ong et al. (2014), computer electricity consumption oscillates depending on the screen size, quality of internet connection, or on the task being executed. For example, video streaming and playback requires more electric power than text typing. However, the estimated consumption rate considered in this work for distance teaching students computers is the circa 2010 manufacturers' specified power consumption of 200W multiplied by the daily average use for two hours (Oliveira et al., 2018), five days per week, forty weeks per year. The total consumption in watt/hour was converted to joules.

4.3.8. Items 11-17: Information flows: the emergy of teaching and learning

According to Odum (1996), the emergy contribution from information to production systems is measured using the information carriers' metabolism and the number of people or percentage of the population in each educational level in a nation as a basis. To calculate the metabolism (J) dispended by students, teachers and tutors during the periods of educational interactivity, the parameter used is the annual 800-hour/year workload prescribed in the curricula. This refers to the time spent in interaction in the classroom, either physical or virtual. To analyze the emergy contribution from information in systems where information transfer processes are relevant, specific UEVs should be used. These UEV values consider the scale of operation, territory and transformity, according to the level of knowledge and experience of an individual performing work – the energy hierarchy of human life (Odum, 1999b). Teachers and students in the Brazilian education system belong to either one of the three education levels: i-basic level, ii- graduation level, or iii- post graduation level, whereas students bring into the system their previously acquired knowledge in one of the following levels: i- non-educated level, ii- basic level, or iii- graduation level. The emergy of such activity derives from multiplying the total energetic metabolism dispended during the periods of interaction by the UEV of teachers and students in each level. The UEVs, in turn, derive from the concurrent national emergy budget (see Table 5) and the size of the population at a given point in time. The UEV is the annual emergy budget divided by the metabolic energy dispended by the population in a given education level during that year. The population division by education level was adapted from the classification found in the IBGE 2010 census, as follows: i- non-educated, ii- basic education level; iii- graduation level; iv- post-graduated, and v- public status. To comply with Odum’s directions, individuals considered as pertaining to a given level of education include those who are still at school, those who have already attained the level in question, and those who evaded from school before finishing the cycle. Due to lack of specific data, the distribution of the population into levels of education is a rough estimate, based on diffuse information collected from different sources, for example, the part of the population who enjoy public status, i.e., people who exert influence over a significant part of the population, were given the same UEV value as that of an individual with a post-graduation degree, assuming the sum of the people in both groups correspond to about 1% of the population. In this work, approaching the estimated real year-to-year UEV value updates for the sixteen-year period covered was attempted, which led to the elaboration of a table containing UEV value approximations for the years between those for which a national emergy budget value had been calculated – 2002, 2004. 2007, 2008, and 2011 (see Giannetti et al, 2017). Since they are associated with a country’s population variations, specifically its distribution into levels of education, and the annual emergy budget, a periodical revision of these UEVs is recommendable so that an emergy accounting effort comes as close as possible to accurate. The gaps between the values published by Giannetti et al. were filled by interpolation, considering a linear increase. The numbers for 2012 onwards derive from a trend line. By linking two known positions in the emergy budget escalade, it is safe to assume that the adopted intermediate values were true in a given moment during the interim. The values found, as well as those of all the other UEVs used herein, are under the 15.83 x 10^{24} sej/yr emergy baseline (see Table 5). Calculation details can be accessed in Appendixes C1 (information from teacher to student), C2 (information from books), and C3 (students' previously acquired information brought into the system).

Table 5. Projections of the emergy budget of Brazil from 2002 to 2017.

Year	Total National Emergy (U) (sej/Yr)	Reference
2002	7.24E+24	Giannetti et al. (2017)
2003	7.70E+24	*
2004	8.15E+24	Giannetti et al. (2017)
2005	8.04E+24	*
2006	7.94E+24	*
2007	7.74E+24	Giannetti et al. (2017)
2008	9.63E+24	Giannetti et al. (2017)
2009	1.06E+25	*
2010	1.28E+25	*
2011	1.39E+25	Giannetti et al. (2017)
2012	1.54E+25	*
2013	1.70E+25	*
2014	1.86E+25	*
2015	2.00E+25	*
2016	2.18E+25	*
2017	2.34E+25	*
2018	2.50E+25	*

Values referenced with an asterisk (*) are estimates obtained from interpolating the previously known values. The estimates for 2012 onwards follow a linear increase tendency, as observed in the previous years.

Figure 4 illustrates the distribution of the population into levels of knowledge and experience, based on approximations developed over IBGE data, and the calculation of the UEVs per joule of work of individuals in each level for the year 2010.

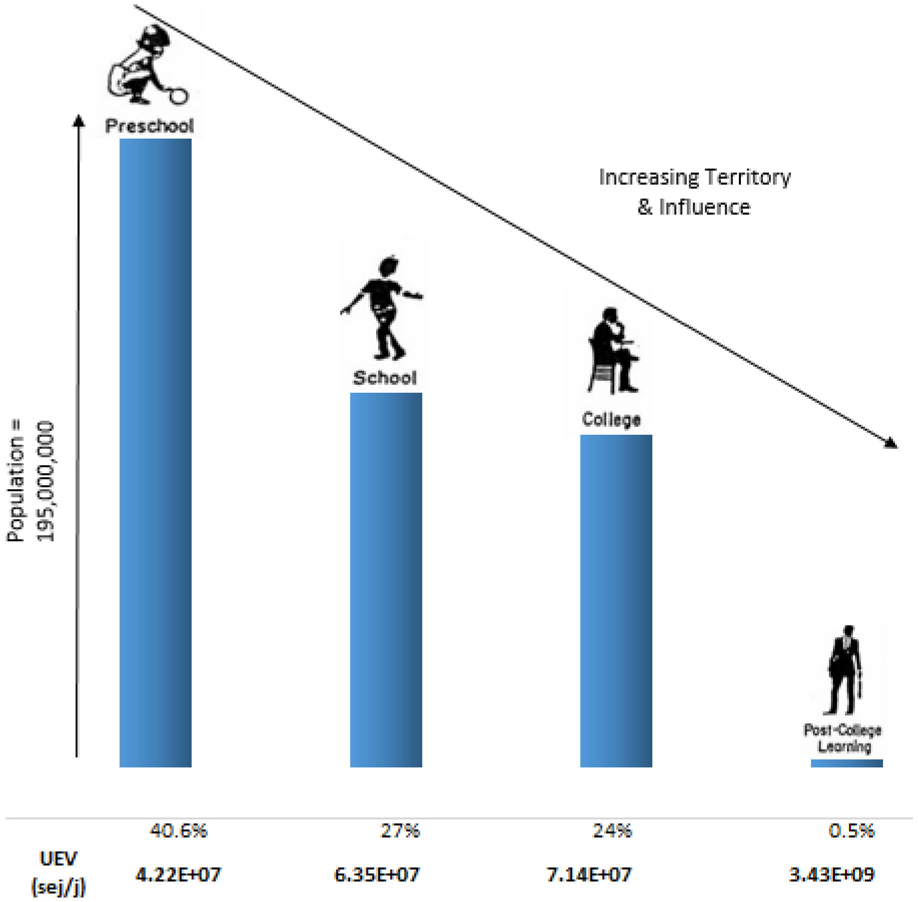


Figure 4. The division of the Brazilian population into levels of knowledge and the UEV per Joule of work of each group member (2010).

Adapted from Odum (1996).

UEV (per level) = National Emergy Budget divided by the annual metabolic energy of the population in each level (3.82 x 10^9 *J/individual/year).*

Table 6 contains annual UEV updates for the work of individuals in all education levels, including teachers and students, based on the population and national emergy budget progression during the timeline covered in this work.

Table 6. UEVs for human labor per education level in function of population and emergy budget increase.

Year	Total National Emergy (U) (sej/Yr)	Final Population Figure for the year	Pre School Level Population	Pre-School Level Energy (J)	**Pre-School Level UEV (sej/J)**	School Level Population	School Level Energy (J)	**School Level UEV (sej/J)**	College Level Population	College Level Energy (J)	**College Level UEV (sej/J)**	Post Grad & Public Status Population Level	Post Grad & Public Status Level Energy (J)	**Post Grad & Public Status Level UEV (sej/J)**
2002	7.24E+24	1.78E+08	8.98E+07	3.43E+17	**2.11E+07**	5.34E+07	2.04E+17	**3.55E+07**	3.02E+07	1.15E+17	**6.28E+07**	8.68E+06	3.32E+16	**2.18E+08**
2003	7.70E+24	1.80E+08	9.09E+07	3.47E+17	**2.22E+07**	5.40E+07	2.06E+17	**3.73E+07**	3.23E+07	1.23E+17	**6.24E+07**	9.55E+06	3.65E+16	**2.11E+08**
2004	8.15E+24	1.82E+08	9.20E+07	3.52E+17	**2.32E+07**	5.47E+07	2.09E+17	**3.90E+07**	3.44E+07	1.31E+17	**6.21E+07**	1.04E+07	3.98E+16	**2.05E+08**
2005	8.04E+24	1.84E+08	7.49E+07	2.86E+17	**2.81E+07**	5.53E+07	2.11E+17	**3.80E+07**	4.43E+07	1.69E+17	**4.75E+07**	1.13E+07	4.31E+16	**1.86E+08**
2006	7.94E+24	1.87E+08	7.58E+07	2.90E+17	**2.74E+07**	5.04E+07	1.93E+17	**4.12E+07**	4.48E+07	1.71E+17	**4.64E+07**	9.33E+05	3.57E+15	**2.23E+09**
2007	7.74E+24	1.89E+08	7.67E+07	2.93E+17	**2.64E+07**	5.10E+07	1.95E+17	**3.97E+07**	4.53E+07	1.73E+17	**4.47E+07**	9.44E+05	3.61E+15	**2.15E+09**
2008	9.63E+24	1.91E+08	7.76E+07	2.96E+17	**3.25E+07**	5.16E+07	1.97E+17	**4.89E+07**	4.59E+07	1.75E+17	**5.50E+07**	9.55E+05	3.65E+15	**2.64E+09**
2009	1.06E+25	1.93E+08	7.85E+07	3.00E+17	**3.54E+07**	5.22E+07	1.99E+17	**5.32E+07**	4.64E+07	1.77E+17	**5.98E+07**	9.66E+05	3.69E+15	**2.87E+09**
2010	1.28E+25	1.95E+08	7.94E+07	3.03E+17	**4.22E+07**	5.28E+07	2.02E+17	**6.35E+07**	4.69E+07	1.79E+17	**7.14E+07**	9.77E+05	3.73E+15	**3.43E+09**
2011	1.39E+25	1.98E+08	8.02E+07	3.06E+17	**4.54E+07**	5.33E+07	2.04E+17	**6.82E+07**	4.74E+07	1.81E+17	**7.67E+07**	9.88E+05	3.77E+15	**3.68E+09**
2012	1.54E+25	2.00E+08	8.11E+07	3.10E+17	**4.97E+07**	5.39E+07	2.06E+17	**7.48E+07**	4.79E+07	1.83E+17	**8.41E+07**	9.98E+05	3.81E+15	**4.04E+09**
2013	1.70E+25	2.02E+08	8.22E+07	3.14E+17	**5.42E+07**	5.46E+07	2.09E+17	**8.14E+07**	4.86E+07	1.86E+17	**9.16E+07**	1.01E+06	3.87E+15	**4.40E+09**
2014	1.86E+25	2.04E+08	8.29E+07	3.17E+17	**5.87E+07**	5.51E+07	2.11E+17	**8.83E+07**	4.90E+07	1.87E+17	**9.94E+07**	1.02E+06	3.90E+15	**4.77E+09**
2015	2.00E+25	2.06E+08	8.36E+07	3.19E+17	**6.26E+07**	5.56E+07	2.12E+17	**9.41E+07**	4.94E+07	1.89E+17	**1.06E+08**	1.03E+06	3.93E+15	**5.08E+09**
2016	2.18E+25	2.07E+08	8.40E+07	3.21E+17	**6.79E+07**	5.59E+07	2.13E+17	**1.02E+08**	4.97E+07	1.90E+17	**1.15E+08**	1.04E+06	3.95E+15	**5.51E+09**
2017	2.34E+25	2.08E+08	8.44E+07	3.23E+17	**7.25E+07**	5.62E+07	2.15E+17	**1.09E+08**	4.99E+07	1.91E+17	**1.23E+08**	1.04E+06	3.97E+15	**5.89E+09**
2018	2.50E+25	2.09E+08	8.49E+07	3.24E+17	**7.71E+07**	5.64E+07	2.16E+17	**1.16E+08**	5.02E+07	1.92E+17	**1.30E+08**	1.05E+06	3.99E+15	**6.26E+09**

Projections developed based on data from IBGE, INEP, and ABED

Considering: Pre-school inhabitants=40.6%; School inhabitants=27%; College Students=24%; Post Graduation inhabitants= 0.5%; Public Status Level = 0.5%

Metabolic energy based on a 2,500 kcal/day diet, or 3.82 E+9 kcal/year.

Annual energy (J) = 3.82 E+9 kcal x 4186 J/kcal x number of inhabitants in a given education level.

UEV of education level (sej/J) = annual national emergy budget/annual metabolic energy of inhabitants in a given education level.

(I) Information from teacher to student

This item is the measure of the work performed by teachers in the information transfer process. The parameter used as a basis for calculations in this work is the total class hours prescribed in the schools' curricula of 800 hours per class group (see Appendix C, Tables A and B). Calculations were performed by education level and sub-level, and the presumed participation of teachers in three different levels of education (I: basic education; II: college education; III: post-graduate) follows the *CNE/SEB Nº 08/2010* document minimum requirements description. The sub-levels and percentage of teachers per education level are illustrated and detailed in Table 7.

Table 7. Teachers' minimum formation level required to operate in different educational levels (CNE/SEB 08/2010).

Sub-level	Teachers holding a high-school degree	Teachers holding a college degree	Teachers holding a post graduation degree
Nursery/Kindergarten	85%	15%	
Primary	40%	60%	
Secondary	40%	60%	
Tertiary (graduation)			100%

Odum (1999b) considers that the energy of learning corresponds to 1% of an individual's metabolic energy dispended over time. This same rate was used by Almeida et al. (2013), and Oliveira et al. (2018).

The INEP synopses do not feature the number of class groups for graduation courses; however, the number of courses is featured. Thus, the estimates under the assumption that every graduation course lasts four years, and has a minimum of four class groups – one for each grade- operating concomitantly, 800 hours per school-year. The emergy calculation procedures are the same as the ones for basic level. In the case of graduation courses, however, only teachers holding a post graduation degree were considered.

(II) Information from books

In this work it is assumed that students absorb 10% from written information. This assumption was based on the work published by Dale (1969) that included the "cone of experience", to base that author's theory that the closer to practical, the greater the absorption of knowledge.

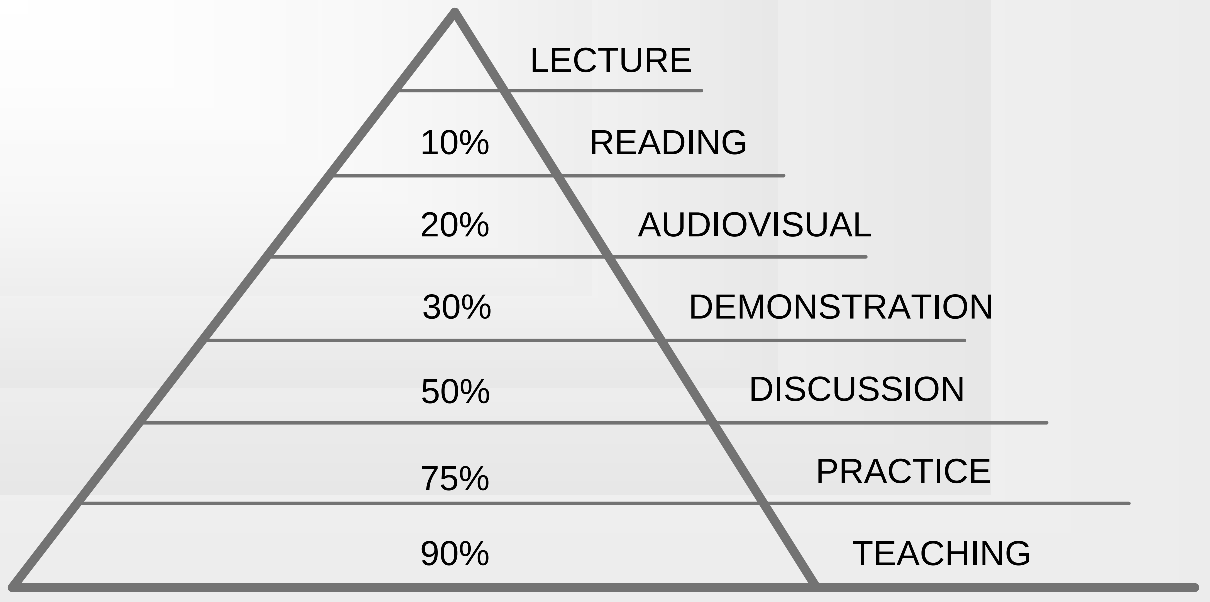


Figure 5. An adaptation of Dale's cone of experience (Dale, 1969).

Books are listed as a form of energy that is periodically fed into the system, in the system operation phase. In the teaching-learning process, books act as information carriers. In this sense, the emergy of the information from books considered in this work equals 10% the emergy of books in the system. The UEV for a Joule of information from technical books was calculated by Oliveira et al. (2018) as a re-contextualization of the UEV calculated by Campbell and Cai (2007).

(III) Information brought into the system by students

The knowledge that was previously obtained by the students either at home before first going to school, or at school, is used by the student as a basis during the process of further learning, and is, therefore, accounted for. Meillaud (2005), Almeida et al. (2013), Oliveira et al. (2018) consider that this contribution amounts to 10% of the energy dispended by the students during their previous education cycles. The calculation, therefore, consists of multiplying the number of students by 4.02×10^7 sej/yr (total joules of metabolic energy spent during the annual curricular 800 hours, multiplied by 0.1), and then multiplied by the corresponding students' current level UEV. On the emergy accounting table, the students' levels are separated into three: I (no previous education), II (basic education), and III (college education).

4.3.9. The Gain-in-Quality Emergy Delivered/Emergy Invested Ratio

In emergy syntheses that consider the intellectual background of an individual’s work contribution to the system, a UEV expressing the level of knowledge that the individual belongs to – non-educated, primary (elementary) level, secondary (high school) level, graduation (higher education), post-graduated - is assigned. The UEVs are variables that result from an equation involving a nation’s current emergy budget, the current population, and the distribution of the inhabitants per the above cited knowledge levels. In this sense, by extending their education process to the next higher level, for instance, enrolling in high school after graduating from elementary school, a student’s work achieves higher quality, and will be measured by the corresponding UEV per joule of work delivered. The student /worker’s final emergy delivery will consequently increase. From the education system’s managerial perspective, the leap in quality results from further investment. An indicator named “the gain-in-quality emergy delivered per emergy invested ratio” is thus put forward. This is a tool designed to check the index of reclamation, whether positive, null, or negative, of the emergy invested in extending education in comparison with the further amount of work delivered, by providing numeric results that can be compared.

5. RESULTS AND DISCUSSION

5.1. Emergy synthesis of the Brazilian Education System

The diagram displays the energy flows that compose and support the infrastructure of the Brazilian education system. The selection of inflows represented in the diagram results from previous analyses carried by Oliveira *et al*.(2018), in which the emergy of a traditional in-class course of Management, and a distance-teaching version of the same course were compared, as for resource use. The items contributing 5% or less to the total system emergy therein were not considered in this study. Figure 6 is the energy systems diagram of the Brazilian educational system infrastructure.

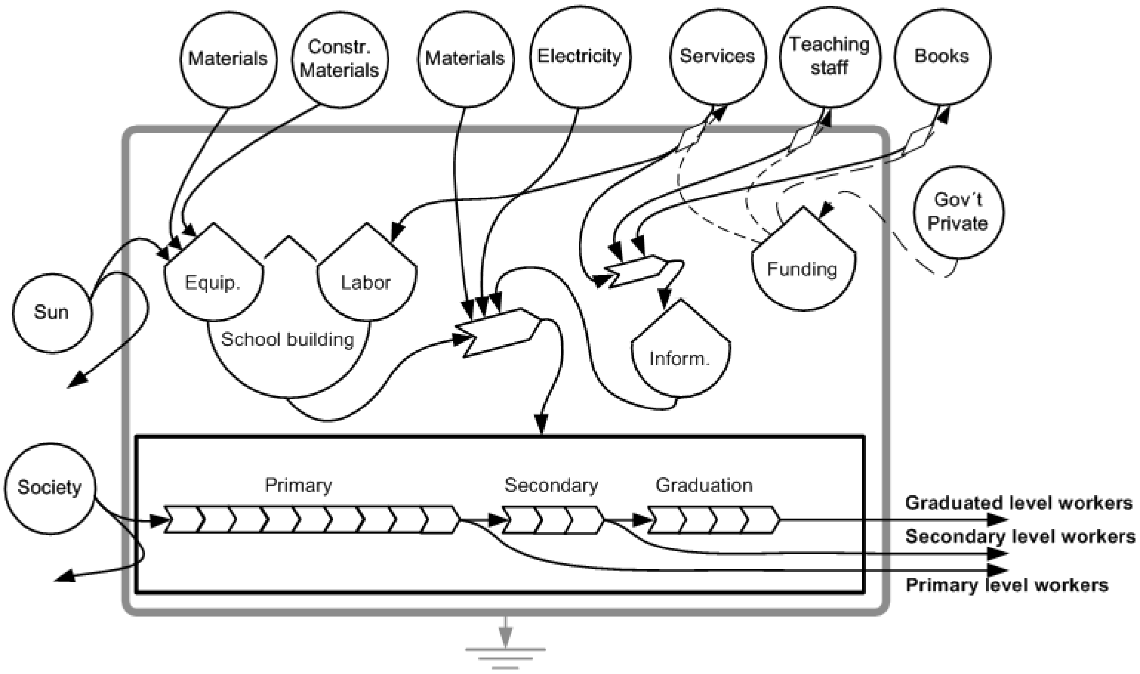


Figure 6. Energy systems language diagram of the Brazilian education system infrastructure.

The upper left-side region of the diagram shows the inputs that compose the physical facilities used in the system, including the buildings, furniture, computers and staff. The storage symbols represent the inputs that persist through time, i.e. items that existed in the system before the analysis timeframe, and are likely to remain in the system past the analysis timeframe. The electricity and materials that enter the infrastructure usage phase, as well as books, and services will continuously enter the system in an "under demand" basis. The intermittent lines represent the flow of money from the government or private maintainers to fund services and the work of teachers. An interaction between books, the teaching staff and services form a stock of information, which, in turn interacts with the infrastructure that the students and teachers will share during the teaching-learning process. A student may leave the system and join the workforce at any moment during the cycle. The outputs from this system are graduation level workers, and workers in one of the lower levels (primary, secondary), thus carrying the respective level UEV, regardless of completing the cycle, or leaving before completion.

(I) Emergy tables

Tables 8 and 8 continued are summarized and feature the total quantity of items calculated for both in-class and distance-teaching systems, and total emergy, only. The total emergy presented refers to the emergy required to support the formal education system as a whole during the year in question. A calculation memorial can be accessed in Appendixes A, B, and C. The full tables for every year from 2002 to 2017 can be accessed in Appendix E.

Table 8. Summarized emergy accounting of the Brazilian education system from 2002 to 2017 (sej/year).

The emergy values comply with the 15.83 x 10^{24} baseline; See Appendix E for a list of UEV references.

Note	Description	**Unit/yr**	**Emergy 2002**	**Emergy 2003**	**Emergy 2004**	**Emergy 2005**	**Emergy 2006**	**Emergy 2007**	**Emergy 2008**	**Emergy 2009**
	Campus implementation									
1	Concrete	g	3.57E+22	3.52E+22	3.50E+22	3.44E+22	3.40E+22	3.29E+22	3.32E+22	3.30E+22
2	Steel	g	2.95E+21	2.92E+21	2.89E+21	2.85E+21	2.81E+21	2.74E+21	2.76E+21	2.73E+21
3	Computer	g	2.36E+21	2.33E+21	2.33E+21	2.31E+21	2.28E+21	2.22E+21	2.25E+21	2.22E+21
	Subtotal		**4.10E+22**	**4.04E+22**	**4.02E+22**	**3.96E+22**	**3.90E+22**	**3.79E+22**	**3.82E+22**	**3.80E+22**
	Campus usage									
4	Electricity	J	4.54E+21	4.52E+21	4.47E+21	4.41E+21	4.35E+21	4.22E+21	4.26E+21	4.21E+21
5	Workbooks	J	1.62E+21	1.64E+21	1.65E+21	1.67E+21	1.67E+21	1.57E+21	1.60E+21	1.59E+21
6	Labor	J	2.95E+22	3.07E+22	3.17E+22	3.05E+22	2.93E+22	2.75E+22	3.43E+22	3.69E+22
	Subtotal		**3.57E+22**	**3.69E+22**	**3.78E+22**	**3.65E+22**	**3.53E+22**	**3.33E+22**	**4.02E+22**	**4.27E+22**
	Access to information									
7	Transportation (steel)	g	5.06E+21	5.15E+21	5.15E+21	5.23E+21	5.23E+21	5.02E+21	5.02E+21	4.98E+21
8	Fuel (diesel)	J	1.51E+22	1.55E+22	1.55E+22	1.57E+22	1.57E+22	1.50E+22	1.51E+22	1.50E+22
9	Computer (students' units)	g	1.19E+19	1.46E+19	7.94E+19	1.24E+20	1.62E+20	1.08E+20	3.12E+20	2.45E+20
10	Electricity	J	3.24E+18	3.99E+18	2.17E+19	3.38E+19	4.43E+19	2.94E+19	8.53E+19	6.68E+19
	Subtotal		**2.02E+22**	**2.06E+22**	**2.07E+22**	**2.11E+22**	**2.11E+22**	**2.02E+22**	**2.06E+22**	**2.03E+22**
	Teaching and Learning									
11	Information Teacher (1) --> Student (1%)	J	1.20E+20	1.28E+20	1.39E+20	1.46E+20	1.62E+20	1.57E+20	1.87E+20	2.17E+20
12	Information Teacher (2) --> Student (1%)	J	2.32E+20	2.33E+20	2.32E+20	2.03E+20	2.00E+20	1.93E+20	2.35E+20	2.64E+20
13	Information Teachers & Tutors (3) --> Student	J	5.08E+19	5.62E+19	6.39E+19	6.44E+19	8.47E+20	8.47E+20	1.17E+21	1.39E+21
14	Information books --> students (10%)	J	1.62E+20	1.64E+20	1.65E+20	1.67E+20	1.67E+20	1.57E+20	1.60E+20	1.59E+20
15	Information brought in by students (1) (10%)	J	5.72E+21	6.24E+21	6.57E+21	8.38E+21	8.00E+21	6.81E+21	9.02E+21	9.63E+21
16	Information brought in by students (2) (10%)	J	6.89E+22	7.28E+22	7.61E+22	7.62E+22	7.94E+22	7.26E+22	8.99E+22	9.76E+22
17	Information brought in by students (3) (10%)	J	8.79E+21	9.73E+21	1.05E+22	8.70E+21	8.99E+21	8.76E+21	1.13E+22	1.23E+22
	Subtotal		**8.40E+22**	**8.94E+22**	**9.38E+22**	**9.38E+22**	**9.78E+22**	**8.96E+22**	**1.12E+23**	**1.22E+23**
	Total Emergy		**1.81E+23**	**1.87E+23**	**1.93E+23**	**1.91E+23**	**1.93E+23**	**1.81E+23**	**2.11E+23**	**2.23E+23**

Table 8 continued

The emergy values comply with the 15.83 x 10^{24} baseline; See Appendix E for a list of UEV references.

Note	Description	**Unit/yr**	**Emergy 2010**	**Emergy 2011**	**Emergy 2012**	**Emergy 2013**	**Emergy 2014**	**Emergy 2015**	**Emergy 2016**	**Emergy 2017**
	Campus implementation									
1	Concrete	g	3.24E+22	3.22E+22	3.22E+22	3.16E+22	3.14E+22	3.11E+22	3.09E+22	3.08E+22
2	Steel	g	2.60E+21	2.66E+21	2.66E+21	2.63E+21	2.60E+21	2.57E+21	2.57E+21	2.56E+21
3	Computer	g	2.19E+21	2.18E+21	2.16E+21	2.14E+21	2.11E+21	2.09E+21	2.08E+21	2.11E+21
	Subtotal		**3.72E+22**	**3.70E+22**	**3.70E+22**	**3.64E+22**	**3.61E+22**	**3.58E+22**	**3.56E+22**	**3.55E+22**
	Campus usage									
4	Electricity	J	4.16E+21	4.12E+21	4.11E+21	4.07E+21	4.02E+21	3.98E+21	3.98E+21	3.94E+21
5	Workbooks	J	1.57E+21	1.58E+21	1.56E+21	1.54E+21	1.54E+21	1.51E+21	1.50E+21	1.50E+21
6	Labor	J	4.33E+22	4.62E+22	5.05E+22	5.44E+22	5.83E+22	6.17E+22	6.66E+22	7.12E+22
	Subtotal		**4.90E+22**	**5.19E+22**	**5.62E+22**	**6.00E+22**	**6.39E+22**	**6.72E+22**	**7.21E+22**	**7.67E+22**
	Access to information									
7	Transportation (steel)	g	4.94E+21	4.90E+21	4.90E+21	4.86E+21	4.86E+21	4.77E+21	4.86E+21	4.81E+21
8	Fuel (diesel)	J	1.48E+22	1.47E+22	1.47E+22	1.46E+22	1.46E+22	1.45E+22	1.46E+22	1.45E+22
9	Computer (students' units)	g	3.10E+20	3.46E+20	3.34E+20	4.06E+20	4.57E+20	4.78E+20	4.91E+20	6.05E+20
10	Electricity	J	8.45E+19	9.47E+19	9.11E+19	1.11E+20	1.25E+20	1.30E+20	1.34E+20	1.65E+20
	Subtotal		**2.01E+22**	**2.00E+22**	**2.00E+22**	**1.99E+22**	**2.00E+22**	**1.98E+22**	**2.01E+22**	**2.00E+22**
	Teaching and Learning									
11	Information Teacher (1) --> Student (1%)	J	2.61E+20	2.89E+20	3.22E+20	3.55E+20	3.88E+20	4.12E+20	4.52E+20	4.40E+20
12	Information Teacher (2) --> Student (1%)	J	3.15E+20	3.45E+20	3.79E+20	4.13E+20	4.45E+20	4.67E+20	5.05E+20	4.58E+20
13	Information Teachers & Tutors (3) --> Student	J	1.73E+21	1.93E+21	2.20E+21	2.45E+21	2.75E+21	2.98E+21	3.06E+21	3.69E+21
14	Information books --> students (10%)	J	1.57E+20	1.54E+20	1.56E+20	1.54E+20	1.54E+20	1.51E+20	1.50E+20	1.50E+20
15	Information brought in by students (1) (10%)	J	1.16E+22	1.29E+22	1.47E+22	1.68E+22	1.89E+22	2.03E+22	2.29E+22	2.52E+22
16	Information brought in by students (2) (10%)	J	1.14E+23	1.21E+23	1.31E+23	1.40E+23	1.50E+23	1.56E+23	1.68E+23	1.79E+23
17	Information brought in by students (3) (10%)	J	1.59E+22	1.81E+22	2.02E+22	2.31E+22	2.63E+22	2.88E+22	3.05E+22	3.31E+22
	Subtotal		**1.44E+23**	**1.54E+23**	**1.68E+23**	**1.83E+23**	**1.98E+23**	**2.09E+23**	**2.26E+23**	**2.42E+23**
	Total Emergy		**2.50E+23**	**2.63E+23**	**2.82E+23**	**2.99E+23**	**3.18E+23**	**3.32E+23**	**3.54E+23**	**3.74E+23**

The results in Tables 8 and 8 continued show that the total emergy required to support the Brazilian education system had increased by 100% at the end of the cycle, in contrast to the decrease in the number of students in every level, except graduation, from 2005 onwards (see Table 12). The emergy decrease from items directly related to the number of enrolled students is surpassed by the emergy resulting from the annual updates for UEV values for teachers and students' work in the information transfer process, i.e. emergy of teaching and learning.

The emergy of human labor involved in the educational activities is a co-product of the annual emergy budget. As opposed to earlier studies involving education systems (Meillaud, 2005; Almeida et al, 2013), in which the resulting emergy of information flows corresponded to approximately 90% of the total emergy of the systems studied by those authors, the results obtained herein ranged from 48% in 2002 to 64% in 2017. Two factors explain the discrepancy: a- the differences in the parameters used for UEV calculation, and b- the method employed to calculate the flows of information in the system (see Appendix D).

During the period covered, the total emergy budget from Brazil increased 13%/year in average, whereas the emergy of the education system grew 6.5%/year, in average. This is due to the fact that the emergy budget of Brazil increases through time due to the increase in “F” (feedback from economy) inputs, which renders the human labor more dependent on external resources, therefore, becoming more expensive resource-wise. The corresponding percentage of the annual national emergy required to support the education system showed successive drops of 0.2% in average, throughout the 16-year timeline, as shown in Table 9.

Table 9. Percentage from the total annual emergy budget of the emergy used to support the Brazilian education system, from 2002 to 2017.

Year	Total Emergy used (sej/yr)	Total National Emergy (U) (sej/yr)	Percentage from total Emergy (U)
2002	1.81E+23	2.77E+24	**6.53%**
2003	1.87E+23	3.80E+24	**4.92%**
2004	1.93E+23	4.80E+24	**4.02%**
2005	1.91E+23	5.70E+24	**3.35%**
2006	1.93E+23	6.40E+24	**3.02%**
2007	1.81E+23	7.74E+24	**2.34%**
2008	2.11E+23	9.00E+24	**2.34%**
2009	2.23E+23	1.06E+25	**2.10%**
2010	2.50E+23	1.28E+25	**1.95%**
2011	2.63E+23	1.39E+25	**1.89%**
2012	2.82E+23	1.54E+25	**1.83%**
2013	2.99E+23	1.70E+25	**1.76%**
2014	3.18E+23	1.86E+25	**1.71%**
2015	3.32E+23	2.00E+25	**1.66%**
2016	3.54E+23	2.18E+25	**1.62%**
2017	3.74E+23	2.34E+25	**1.60%**

In comparison, the percentage of the annual national emergy budget used to support the education system in 2002-2004 was relatively close, in numbers, to the percentage from the national GDP expended in education - 5.25% in average, from 2000 to 2015 (INEP/MEC, 2015)- These numbers are also close to those from other countries in the Americas in 2018, such as Argentina (5.3%), Colombia (4.7%), Chile (4.8%), Mexico (5.3%), and the United States (5.4%) (MINISTÉRIO DA FAZENDA, 2018). Figure 7 compares the emergy budget percentage and GDP percentage investment in education in Brazil from 2002 to 2015. A higher variation per unit time occurs for the national emergy budget than for the emergy supporting the education system. In the sixteen-year interim, the national emergy budget increased 220%, whereas the emergy demanded by the education system increased 100%, therefore, the decreasing percentage of the emergy budget invested. It is also noteworthy that the number of active schools and enrolled students has been decreasing since 2004, however, the total emergy of the education system, conversely, increases every year due to UEV value updates.

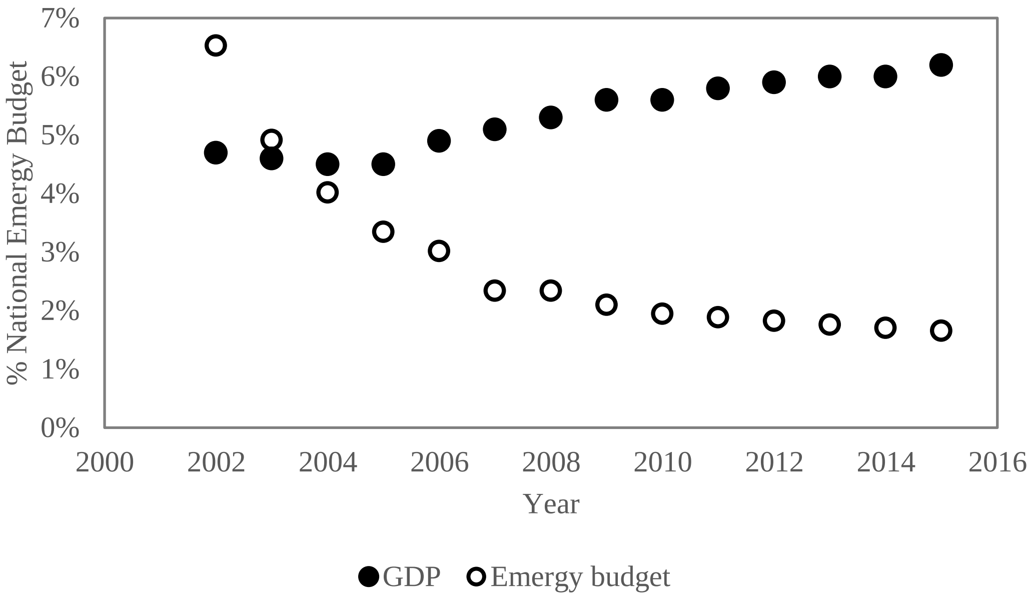


Figure 7. Percentage of national emergy budget supporting the education system and percentage from GDP invested in education compared.

Adapted from INEP

The emergy that supports the national formal education system is basically contributed by two parties: the institutions and the students. While the institutions provide the infrastructure, facilities and services, they may be partly responsible for the emergy use involved in transportation of students, and materials. Students contribute transportation (partly), personal computers as pedagogic tools, as is the case of distance teaching, unsubsidized books, which is the case of students in private institutions, and the load of previously acquired information. A calculation of the students' contribution to the total emergy of the system throughout the timeline was made (Table 10). Due to the lack of official data, the amount of emergy contribution from transportation backed by students are mere assumptions; the emergy of books was calculated considering that, in the timeline average, approximately 20% of the students are in private schools, and therefore do not use government-subsidized books. The results show that the emergy input from the students in the total system energy is steadily increasing, in fact, nearly tripling in 16 years. Most of the emergy contributed comes from the basic school students' previously acquired information (Previous Info level II). This is due to the numerical predominance of basic school students in the system.

Table 10 Emergy contribution brought into the system by the students (sej/year)

Year	**Total System Emergy**	50% Transportation	50% Fuel	Computers	Electricity	20% books	20% info from books	Previous Info level I	Previous Info level II	Previous Info level III	**Total Students' emergy input**	**Students' input percentage**
2002	**1.81E+23**	2.53E+21	7.57E+21	1.19E+19	3.24E+18	3.25E+20	3.25E+19	2.19E+21	2.64E+22	3.36E+21	**4.24E+22**	**23.4%**
2003	**1.87E+23**	2.57E+21	7.74E+21	1.46E+19	3.99E+18	3.28E+20	3.28E+19	3.06E+21	3.59E+22	4.80E+21	**5.45E+22**	**29.1%**
2004	**1.93E+23**	2.57E+21	7.74E+21	7.94E+19	2.17E+19	3.30E+20	3.30E+19	3.88E+21	4.49E+22	6.20E+21	**6.58E+22**	**34.1%**
2005	**1.91E+23**	2.61E+21	7.85E+21	1.24E+20	3.38E+19	3.35E+20	3.35E+19	5.93E+21	5.41E+22	6.17E+21	**7.72E+22**	**40.4%**
2006	**1.93E+23**	2.61E+21	7.85E+21	1.62E+20	4.43E+19	3.34E+20	3.34E+19	6.46E+21	6.40E+22	7.25E+21	**8.88E+22**	**46.0%**
2007	**1.81E+23**	2.51E+21	7.51E+21	1.08E+20	2.94E+19	3.15E+20	3.15E+19	6.81E+21	7.26E+22	8.76E+21	**9.87E+22**	**54.5%**
2008	**2.11E+23**	2.51E+21	7.57E+21	3.12E+20	8.53E+19	3.20E+20	3.20E+19	8.43E+21	8.41E+22	1.06E+22	**1.14E+23**	**54.0%**
2009	**2.23E+23**	2.49E+21	7.51E+21	2.45E+20	6.68E+19	3.18E+20	3.18E+19	9.63E+21	9.76E+22	1.23E+22	**1.30E+23**	**58.4%**
2010	**2.50E+23**	2.47E+21	7.40E+21	3.10E+20	8.45E+19	3.14E+20	3.14E+19	1.16E+22	1.14E+23	1.59E+22	**1.52E+23**	**60.9%**
2011	**2.63E+23**	2.45E+21	7.35E+21	3.46E+20	9.47E+19	3.07E+20	3.07E+19	1.29E+22	1.21E+23	1.81E+22	**1.62E+23**	**61.7%**
2012	**2.82E+23**	2.45E+21	7.35E+21	3.34E+20	9.11E+19	3.11E+20	3.11E+19	1.47E+22	1.31E+23	2.02E+22	**1.76E+23**	**62.4%**
2013	**2.99E+23**	2.43E+21	7.29E+21	4.06E+20	1.11E+20	3.08E+20	3.08E+19	1.68E+22	1.40E+23	2.31E+22	**1.90E+23**	**63.6%**
2014	**3.18E+23**	2.43E+21	7.29E+21	4.57E+20	1.25E+20	3.07E+20	3.07E+19	1.89E+22	1.50E+23	2.63E+22	**2.05E+23**	**64.6%**
2015	**3.32E+23**	2.39E+21	7.23E+21	4.78E+20	1.30E+20	3.01E+20	3.01E+19	2.03E+22	1.56E+23	2.88E+22	**2.16E+23**	**64.9%**
2016	**3.54E+23**	2.43E+21	7.29E+21	4.91E+20	1.34E+20	2.99E+20	2.99E+19	2.29E+22	1.68E+23	3.05E+22	**2.32E+23**	**65.6%**
2017	**3.74E+23**	2.41E+21	7.23E+21	6.05E+20	1.65E+20	2.99E+20	2.99E+19	2.52E+22	1.79E+23	3.31E+22	**2.48E+23**	**66.3%**

The weight of human labor in teaching and learning activities over the system's total emergy is evident in Table 10, since the contribution from students doubled along with the gradual reduction of the system as a result of the linear UEV updates. As illustrated in Figure 8, the percentage of students' relative contribution ranged from 25% to 65%, in the course of the 16-year timeline.

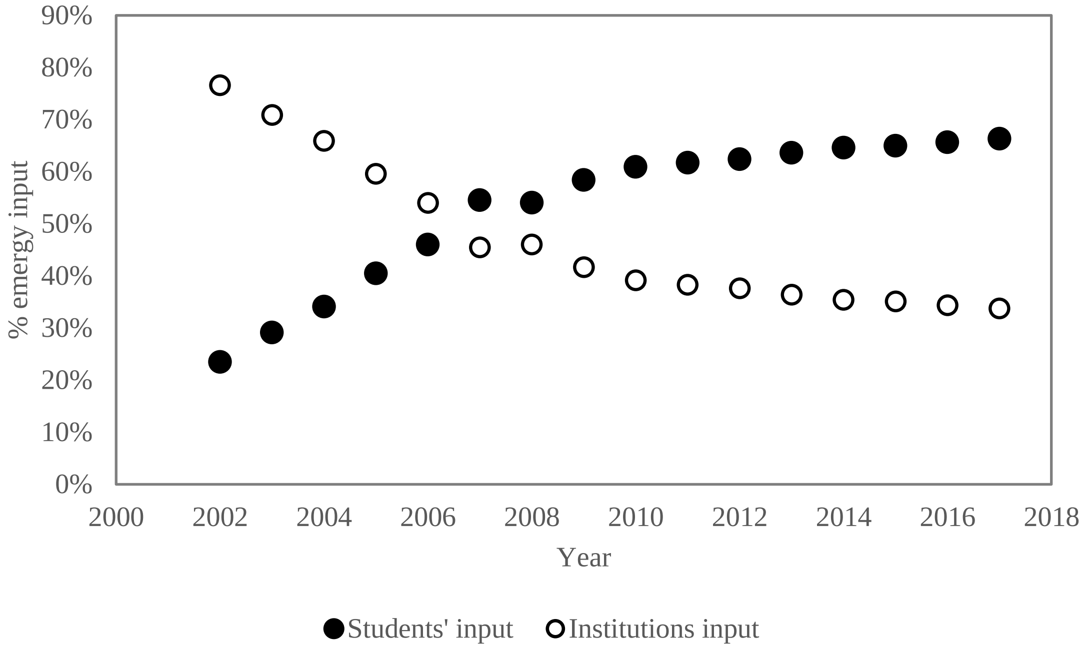


Figure 8. Students input vs. institutions input to system's total emergy, from 2002 to 2017.

As per the assumptions made in this work, the neutral point occurred between 2006 and 2007, when the contribution from both parts were equal. Different plausible assumptions as for the amount of emergy from transportation, fuel, computers, electricity, and books would not cause significant impact on the final result, since the total emergy of information-related activities, for example, are one order of magnitude higher than transportation, and even further away from the remaining items. Removing the information-related inputs (IRI) from the calculation would cause the students' contribution to drop gradually from about 6% in the first year to about 3% in the last, as seen in Table 11.

Table 11. Emergy of students inputs except information-related emergy.

Year	Total System Emergy	50% Transportation	50% Fuel	Computers	Electricity	20% books	Total	Students' input percentage
2002	**1.81E+23**	2.53E+21	7.57E+21	1.19E+19	3.24E+18	3.25E+20	**1.04E+22**	**5.8%**
2003	**1.87E+23**	2.57E+21	7.74E+21	1.46E+19	3.99E+18	3.28E+20	**1.07E+22**	**5.7%**
2004	**1.93E+23**	2.57E+21	7.74E+21	7.94E+19	2.17E+19	3.30E+20	**1.07E+22**	**5.6%**
2005	**1.91E+23**	2.61E+21	7.85E+21	1.24E+20	3.38E+19	3.35E+20	**1.10E+22**	**5.7%**
2006	**1.93E+23**	2.61E+21	7.85E+21	1.62E+20	4.43E+19	3.34E+20	**1.10E+22**	**5.7%**
2007	**1.81E+23**	2.51E+21	7.51E+21	1.08E+20	2.94E+19	3.15E+20	**1.05E+22**	**5.8%**
2008	**2.11E+23**	2.51E+21	7.57E+21	3.12E+20	8.53E+19	3.20E+20	**1.08E+22**	**5.1%**
2009	**2.23E+23**	2.49E+21	7.51E+21	2.45E+20	6.68E+19	3.18E+20	**1.06E+22**	**4.8%**
2010	**2.50E+23**	2.47E+21	7.40E+21	3.10E+20	8.45E+19	3.14E+20	**1.06E+22**	**4.2%**
2011	**2.63E+23**	2.45E+21	7.35E+21	3.46E+20	9.47E+19	3.07E+20	**1.05E+22**	**4.0%**
2012	**2.82E+23**	2.45E+21	7.35E+21	3.34E+20	9.11E+19	3.11E+20	**1.05E+22**	**3.7%**
2013	**2.99E+23**	2.43E+21	7.29E+21	4.06E+20	1.11E+20	3.08E+20	**1.05E+22**	**3.5%**
2014	**3.18E+23**	2.43E+21	7.29E+21	4.57E+20	1.25E+20	3.07E+20	**1.06E+22**	**3.3%**
2015	**3.32E+23**	2.39E+21	7.23E+21	4.78E+20	1.30E+20	3.01E+20	**1.05E+22**	**3.2%**
2016	**3.54E+23**	2.43E+21	7.29E+21	4.91E+20	1.34E+20	2.99E+20	**1.06E+22**	**3.0%**
2017	**3.74E+23**	2.41E+21	7.23E+21	6.05E+20	1.65E+20	2.99E+20	**1.07E+22**	**2.9%**

A comparison of the emergy inputs from students with and without information-related emergy is illustrated in Figure 9.

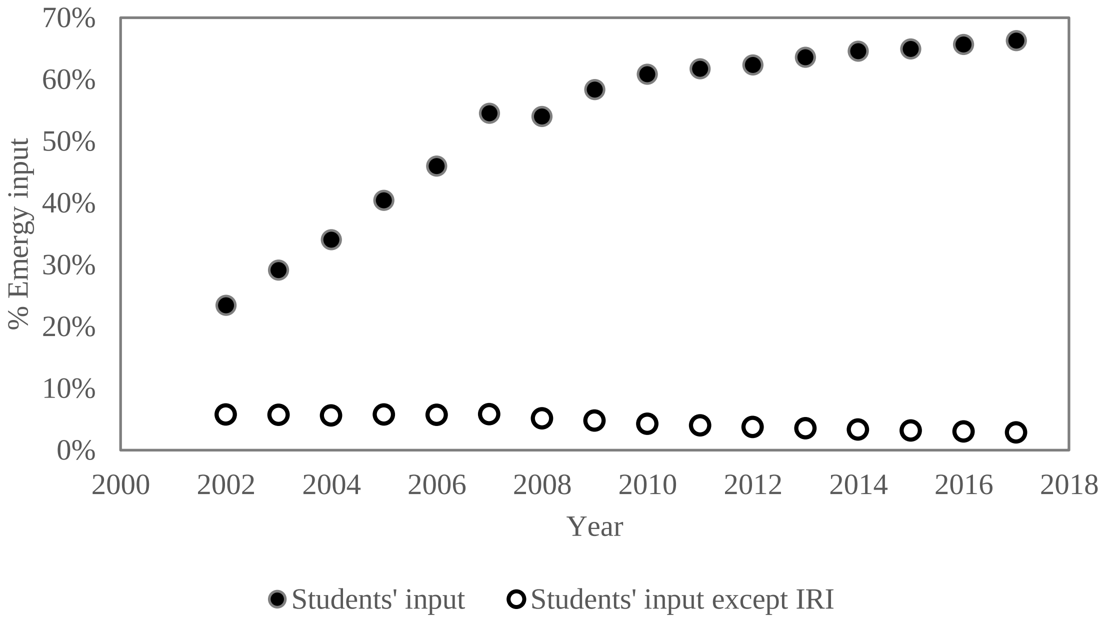


Figure 9. Students' input (with information-related inputs versus without information-related inputs).

5.2. Emergy investment in the formation of human capital: the total global emergy and EPS required to form laborers of different levels of knowledge.

The aim of this segment is to present an estimation of the emergy invested in the formation of workers at different education levels. The proposed simulation considers a full, continuous cycle, without interruptions or repetitions. Such continuity is far from being common sense, as suggested by the INEP annual reports. An example of such discontinuity in the formation cycle of a large number of students, using the numbers from the INEP reports of a randomly chosen point in the timeline, is the fact that 2.5 million students successfully concluded the last (8th) Primary school grade in 2004, while the number of enrolled students for the 1st grade of Secondary school in 2005 reached 3.6 million. This suggests that one-third of the new secondary school students are resuming their cycle in 2005, after a temporary interruption.

The calculations of the accumulated emergy invested in the full education cycle -basic school and graduation- from 2002 to 2017, as well as the emergy required, in the same interim, to form individuals (EPS) who will join the workforce is presented. With adjustments made necessary by the restrictions in the amount of the available data that were collected to form the time line, these calculations are based on the accumulated emergy in the 2002-2017 interim, which covers a full regular basic school to graduation cycle, considering primary school as a 9-year cycle (Federal Law No. 11.114/2005).

Table 12. Primary and secondary schools participation percentage in the enrollments totals from 2002 to 2017.

YEAR	TOTAL	Regular Primary School	% from total	High school	Y & A program	Vocational school	Sub-total	% from total
2002	58,423,667	35,150,362	60.16%	8,710,584	3,779,593	565,042	13,055,219	22.35%
2003	59,383,355	34,438,749	57.99%	9,072,942	4,403,436	589,383	14,065,761	23.69%
2004	59,502,647	34,012,434	57.16%	9,169,357	4,577,268	676,093	14,422,718	24.24%
2005	60,546,704	33,534,561	55.39%	9,031,302	5,615,409	707,263	15,353,974	25.36%
2006	60,243,205	33,282,663	55.25%	8,906,820	5,616,291	744,690	15,267,801	25.34%
2007	56,918,493	31,733,198	55.75%	8,264,816	4,940,165	682,431	13,887,412	24.40%
2008	57,354,494	31,694,497	55.26%	8,272,159	4,902,374	790,142	13,964,675	24.35%
2009	57,443,661	31,705,528	55.19%	8,337,160	4,661,332	861,114	13,859,606	24.13%
2010	56,780,738	31,005,341	54.61%	8,357,675	4,287,234	924,670	13,569,579	23.90%
2011	57,209,040	30,490,476	53.30%	8,401,829	4,082,528	1,483,643	13,968,000	24.42%
2012	57,010,104	29,826,627	52.32%	8,377,942	3,961,925	1,605,608	13,945,475	24.46%
2013	56,759,524	29,187,602	51.42%	8,314,048	3,830,207	1,667,685	13,811,940	24.33%
2014	56,827,468	28,571,512	50.28%	8,301,380	3,653,530	1,945,006	13,899,916	24.46%
2015	56,022,196	27,931,210	49.86%	8,076,150	3,491,869	1,917,192	13,485,211	24.07%
2016	55,991,019	27,691,478	49.46%	8,133,040	3,482,174	1,859,940	13,475,154	24.07%
2017	55,746,595	27,348,080	49.06%	7,930,384	3,598,716	1,831,003	13,360,103	23.97%

The calculations performed in this section considered the distribution of the population into levels of education, as reported by the official Census (IBGE 2000 and 2010), which served as a guide in the calculation of UEVs for human labor in this work. However, in this section, the numbers for basic education were split into primary and secondary school levels, based on the participation percentage of each of these sub-levels in the total system emergy (see Table 12). In this sense, the emergy of primary school was combined with the emergy of preschool and elementary school, whereas the emergy of high school includes the emergy of regular high school, Youth and Adults Education program, and vocational school. The remaining percentage refers to graduation school. The accumulated emergy invested in each one of the levels is presented in Tables 13 and 14, and considers a full schooling career without school grade repetition due to failure. The emergy required during the 2002-2017 cycle is highlighted. As a result from the emergy accounting of the education system in every year of the time line, these numbers can be regarded herein as an approximation of the real emergy invested in the system's full education cycle, and in a student's education cycle. Since the focus of this work is the total emergy supporting the education system in its entirety, the emergy value assigned to each level results from the percentage of participation by each level in the total system emergy, based on the global emergy-per-student, i.e., total emergy divided by total student body, regardless of level. Therefore, the emergy supporting each level or variation is diluted into one global emergy value, and the resulting EPS is based on the participation of each student in the entire system.

Table 13. Emergy investment in the full education cycle from 2002 to 2017, except post-graduation (sej).

YEAR	Primary School emergy total per year (sej)	Secondary School emergy total per year (sej)	Graduation emergy total per year(sej)
2002	**1.09E+23**	4.04E+22	1.09E+22
2003	**1.08E+23**	4.43E+22	1.24E+22
2004	**1.10E+23**	4.72E+22	1.37E+22
2005	**1.06E+23**	5.19E+22	1.44E+22
2006	**1.06E+23**	4.94E+22	1.56E+22
2007	**1.00E+23**	4.39E+22	1.66E+22
2008	**1.15E+23**	5.18E+22	2.11E+22
2009	**1.21E+23**	5.30E+22	2.28E+22
2010	**1.34E+23**	5.90E+22	2.76E+22
2011	1.38E+23	**6.34E+22**	3.05E+22
2012	1.45E+23	**6.78E+22**	3.41E+22
2013	1.51E+23	**7.19E+22**	3.77E+22
2014	1.56E+23	7.67E+22	**4.28E+22**
2015	1.62E+23	7.86E+22	**4.64E+22**
2016	1.71E+23	6.61E+22	**4.96E+22**
2017	1.78E+23	6.80E+22	**5.39E+22**

Table 14. Emergy investment per education level in the full education cycle from 2002 to 2017, except post-graduation – summary.

Emergy invested in Primary school cycle 2002-2010 (sej)	1.01E+24
Emergy invested in Secondary school cycle 2011-2013 (sej)	2.03E+23
Emergy invested in Graduation school cycle 2014-2017 (sej)*	1.93E+23
Accumulated emergy by the end of cycle 2002-2017 (sej)	**1.41E+24**

* Considering an average 4-year graduation program

According to the results in Tables 13 and 14, the final amount of emergy required to support the full education cycle of the Brazilian education system during the 16 years covered in the timeline corresponded to 6% the 2017 national emergy budget approximated in this work. In average, 77% of the institutions operating in the interim were public schools. Therefore, the government financial budget allocation to support the full 2002-2017 education cycle accounted for approximately 1.08 x 10^{24} sej. The Primary level demanded the largest emergy support, as it contained the largest number of students overall. The emergy required to form individuals –

emegy per student - in different levels (primary, secondary, and graduation) is shown in Table 15 and Table 16.

Table 15. EPS investment in the full education cycle from 2002 to 2017 (sej/student).

YEAR	Primary school EPS total per year(sej/student)	Secondary school EPS total per year (sej/student)	Graduation school EPS total per year (sej/student)
2002	**1.86E+15**	1.39E+16	1.86E+14
2003	**1.82E+15**	1.33E+16	2.08E+14
2004	**1.85E+15**	1.32E+16	2.30E+14
2005	**1.74E+15**	1.16E+16	2.37E+14
2006	**1.76E+15**	1.25E+16	2.58E+14
2007	**1.75E+15**	1.30E+16	2.90E+14
2008	**1.98E+15**	1.48E+16	3.63E+14
2009	**2.08E+15**	1.61E+16	3.91E+14
2010	**2.33E+15**	1.84E+16	4.79E+14
2011	2.37E+15	**1.88E+16**	5.23E+14
2012	2.49E+15	**2.02E+16**	5.87E+14
2013	2.60E+15	**2.15E+16**	6.51E+14
2014	2.69E+15	2.27E+16	**7.36E+14**
2015	2.81E+15	2.44E+16	**8.08E+14**
2016	2.97E+15	2.60E+16	**8.62E+14**
2017	3.09E+15	2.77E+16	**9.37E+14**

Table 16. EPS investment per education level in a full education cycle 2002-2017, except post-graduation (sej) – summary.

Emergy per student invested in Primary school cycle 2002-2010 (sej)	1.72E+16
Emergy per student invested in Secondary school cycle 2011-2013 (sej)	6.04E+16
Emergy per student invested in Graduation school cycle 2014-2017 (sej)*	3.34E+15
Accumulated emergy by the end of cycle 2002-2017 (sej)	**8.09E+16**

* Considering an average 4-year graduation program

The numbers are consistent with the fact that the secondary school holds the lowest number of students per emergy total invested, hence the highest EPS (6.04 x 10^{16} sej). The best EPS ratio was achieved by the graduation school.

5.3. A hypothetical full-shift to distance teaching

As the adoption of DT as an alternative to achieve formal education grows, along with the encouragement from educational authorities in the sense of using DT to fill gaps in the educational system, a huge difference in the amount and types of resources to back the system, in comparison with the system as is, is obvious, with distinct impacts on the final amount of emergy required to back it. In this section, simulations were made, based on the statistic data from the years covered in the time series with the aim of estimating the emergy required to support the education system under a hypothetical full migration to distance teaching as the mode of choice to attain formal basic and higher education. Preliminary calculations were performed by Oliveira and Almeida (2019) using data for 2015. Moreover, the required emergy investment to form individuals holding primary school, high school, and graduation degrees from the year 2002 to 2017 was also calculated. The results derive from a previously calculated EPS for each input, multiplied by the total number of attending students for both modes. The emergy required for all the school years covered in the time series was then re-calculated using the distance teaching EPS as a basis; the results showed total emergy variations ranging from -11% (2010) to + 274% (2006), in comparison with the results for the actual scenarios for each year. Therefore, in order to build scenarios for comparisons in this section, a decision was made to use the actual EPS numbers for each year, from 2002 to 2017, instead of an average value. The resulting differences in emergy requirements for each phase were also analyzed. Table 17 is a sample that includes the percentage variations in case of full migration to Distance Teaching, for the year 2017. A full comparative view of the emergy, EPS, and emergy of a full migration to Distance Teaching for the years 2002-2017 can be accessed in Appendix D2. Charts follow the discussion of each result.

Table 17. Percentage variations per phase in case of a full migration to distance teaching.

2017	**In-class system emergy (sej/yr)**	**DT system emergy (sej/yr)**	**System global (in-class + DT) emergy (sej/yr)**	**Full-shift to DT emergy (sej/yr)**	**Variation (%)**
Campus/DTC implementation	3.51E+22	3.91E+20	**3.55E+22**	**1.28E+22**	**-64%**
Campus/DTC usage	6.56E+22	1.41E+21	**6.70E+22**	**4.60E+22**	**-31%**
Access to information	1.93E+22	7.71E+20	**2.00E+22**	**2.52E+22**	**+26%**
Teaching and Learning	2.32E+23	9.54E+21	**2.42E+23**	**3.12E+23**	**+29%**
Total emergy			**3.64E+23**	**3.96E+23**	**+9%**

A steep decrease in the implementation and usage of constructed facilities can be observed in Table 17, due to the reduced dimensions of DTCs in comparison to regular school *campi*. In contrast, a higher amount of energy would be required to support the students' access to the environment where he/she will receive formative information, by switching from using motorized vehicles for round trips to school to using computers to access the virtual environment, in a full distance teaching educational system context. The increase in the emergy of teaching and learning may be considered an advantage, in social terms, as it exclusively employs higher-UEV teachers, i.e. teachers holding a post-graduation degree, to accomplish the job of teaching. However, this also suggests that an exclusively distance teaching system is less resource-use efficient, for the same reason, in comparison with the system as is. These comparisons are illustrated in the next section, in charts that also include the years when the shortest and the largest gaps occurred, respectively, between the EPS for the actual mix of school campuses and DTCs, for the sake of comparison.

(I) School campi vs. DTCs

The figures considering a hypothetical full shift to distance teaching in Table 17 derive from using the EPS for the year 2017 as the multiplication factor. It is worth noting that neither the total number of operational traditional school campi nor the total number of active DTCs for a given year is dependent on the number of students. The EPS unit, however, varies in function of the number of students sharing the available facilities, i.e., the more students sharing a given item, the lower the EPS ratio. All simulations for 2017 were performed under this perspective. By said system configuration featuring a mix of traditional schools and distance teaching in 2017, the total emergy would be reduced to one-third of the current value. The lowest ratio can be seen for 2014, when the DT emergy corresponded to roughly 13% of the traditional system total. In Figure 10 the scenario for 2017 is compared with scenarios representing the time periods featuring the smallest and the largest gaps between invested emergy totals for each scenario, in this case, the years 2004 and 2014, respectively. This same procedure was adopted for the charts for the three remaining phases.

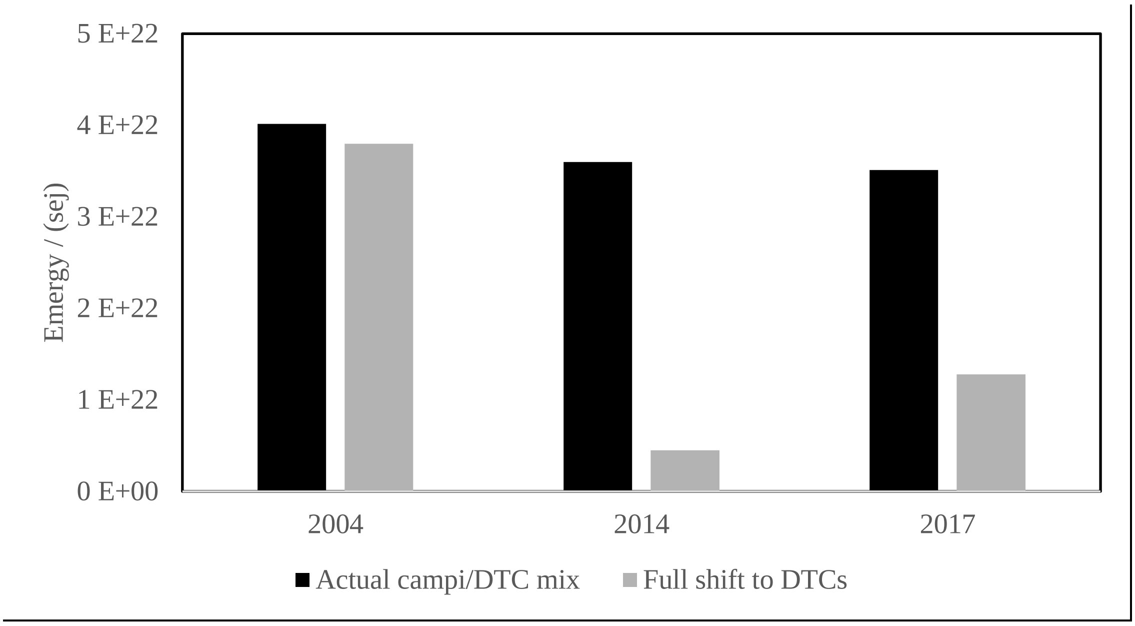


Figure 10. Emergy of the actual mix of physical facility types compared to the emergy resulting from a hypothetical full shift to distance teaching centers.

(II) Campus usage vs. DTC usage

Using the EPS ratio for this calculation implies that the basic DTC staff configuration and electricity consumption adopted in this work is maintained, and then proportionally multiplied. Figure 11 reveals the descending curve of EPS starting in 2004, as a result from the increasing students' adhesion to distance teaching. The resulting figure shows that 60% less energy would be required to operate the DTCs, in comparison with the energy required to operate traditional campi in 2014. The drop in electricity use and labor are the greatest contributors to this positive comparison. As with the previous figure, Figure 12 shows three scenarios: i- the least effective EPS for the usage phase, which occurs in 2003, the most effective EPS, in 2014, and the EPS for 2017, according to officially published figures.

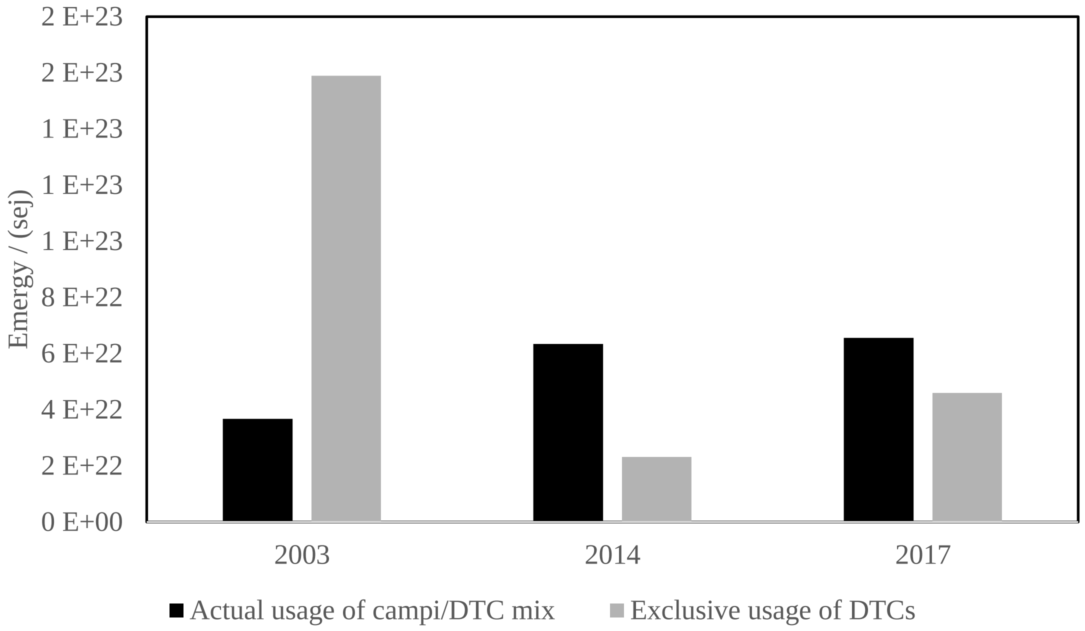


Figure 11. Emergy of the actual usage of a mix of campi and DTCs compared to the emergy of a hypothetical exclusive usage of DTCs.

(III) Accessing information

In comparison, the UEV value for a gram of computer is nearly 20 times the value for a gram of fuel-driven vehicles. Despite the huge difference in total weight between units of one and of the other, the embodied energy in the total of computers required to support a full-migration of students to distance teaching supplants the total emergy used to make vehicles used for transportation to physical schools by about 300%. A compensation might come from the fact that the emergy of the electricity required to feed the students' personal computers amounts to about one-third the emergy of the diesel oil required to feed the vans. The total emergy required to access information, however, would increase by 26%, should all the students use computers exclusively for educational purposes for two hours a day, five days a week. The access to information is, therefore, one weak point, i.e. less efficient, of a full distance teaching system, in emergy terms, in comparison with the traditional system.

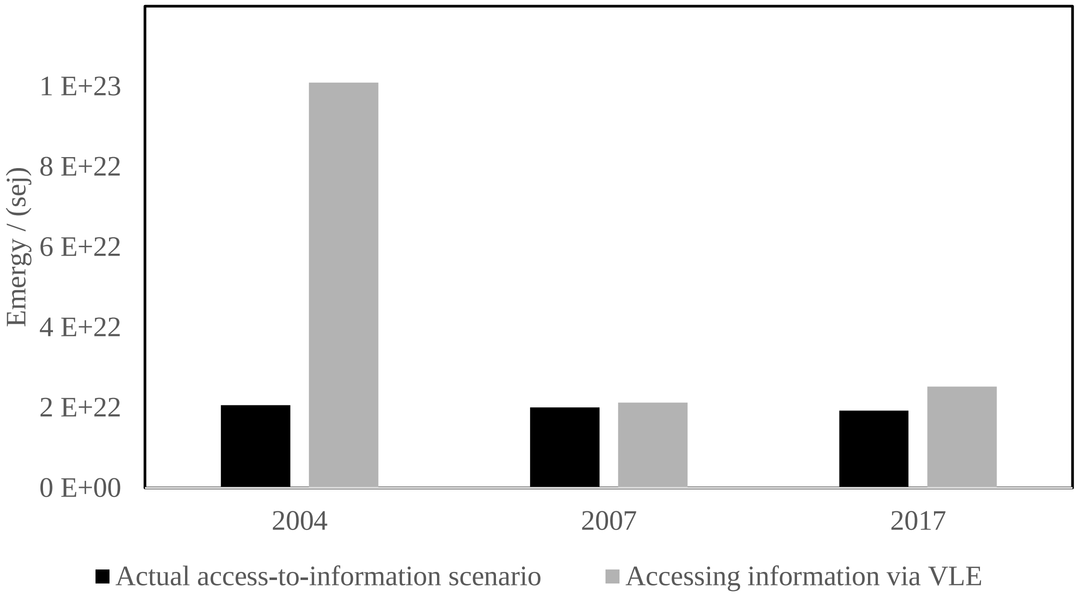


Figure 12. Emergy of the actual forms of accessing information compared to the emergy of exclusively accessing information via VLE.

(IV) Emergy of teaching and learning

Two factors drive upwards the EPS ratio of teaching and learning in Distance Teaching courses, as calculated in this work, when compared to the EPS of the actual system: i- the fact that the majority of the DT students are in graduation courses, and ii- the fact that only teachers holding a post-graduation degree were considered in the calculations. Multiplying the EPS factor by the totality of students in the system results in a nearly 30% increase in the quality of the information flowing in the systems. The largest gap between values is in the year 2004, while the smallest gap is in the year 2014. Both are presented in comparison with the results for the year 2017, in Figure 13.

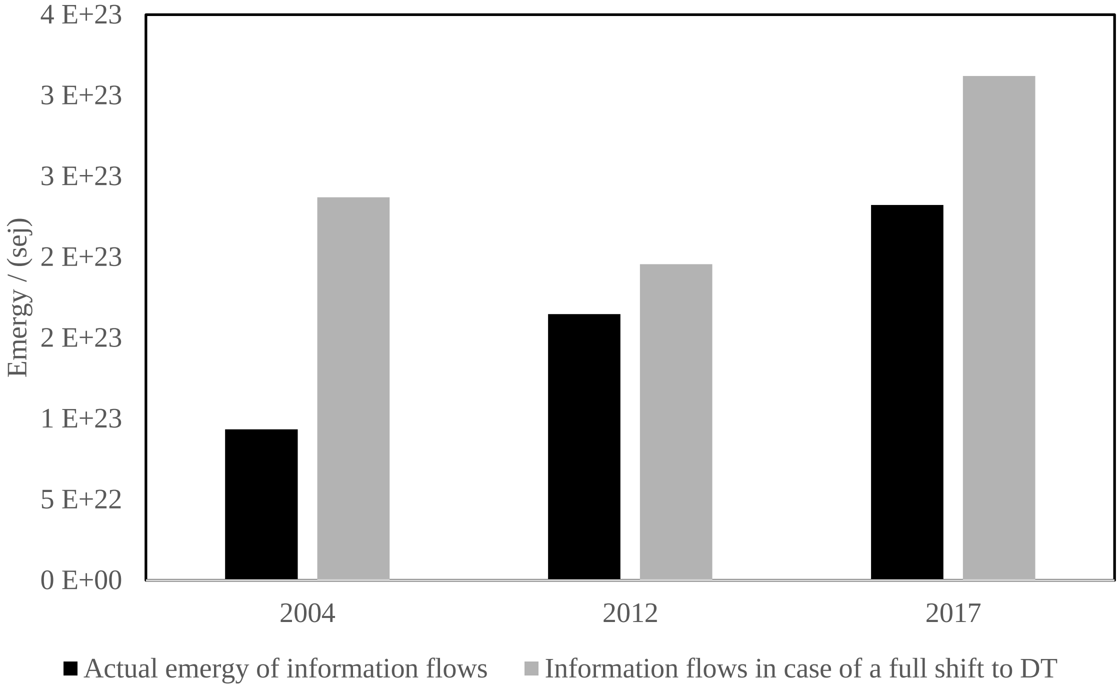


Figure 13. Actual emergy of information flowing in the system compared to the hypothetical emergy of teaching and learning exclusively via the VLE.

(V) Hypothetical full-migration-to-DT EPS behavior compared to the actual EPS throughout the time line

The following series of charts depict the phase-by-phase variations in EPS ratio after a hypothetical full migration from traditional schools to distance teaching, enabling for a direct comparison between the actual EPSs (gray dots) and the new EPSs (white dots) that derive in case of a migration.

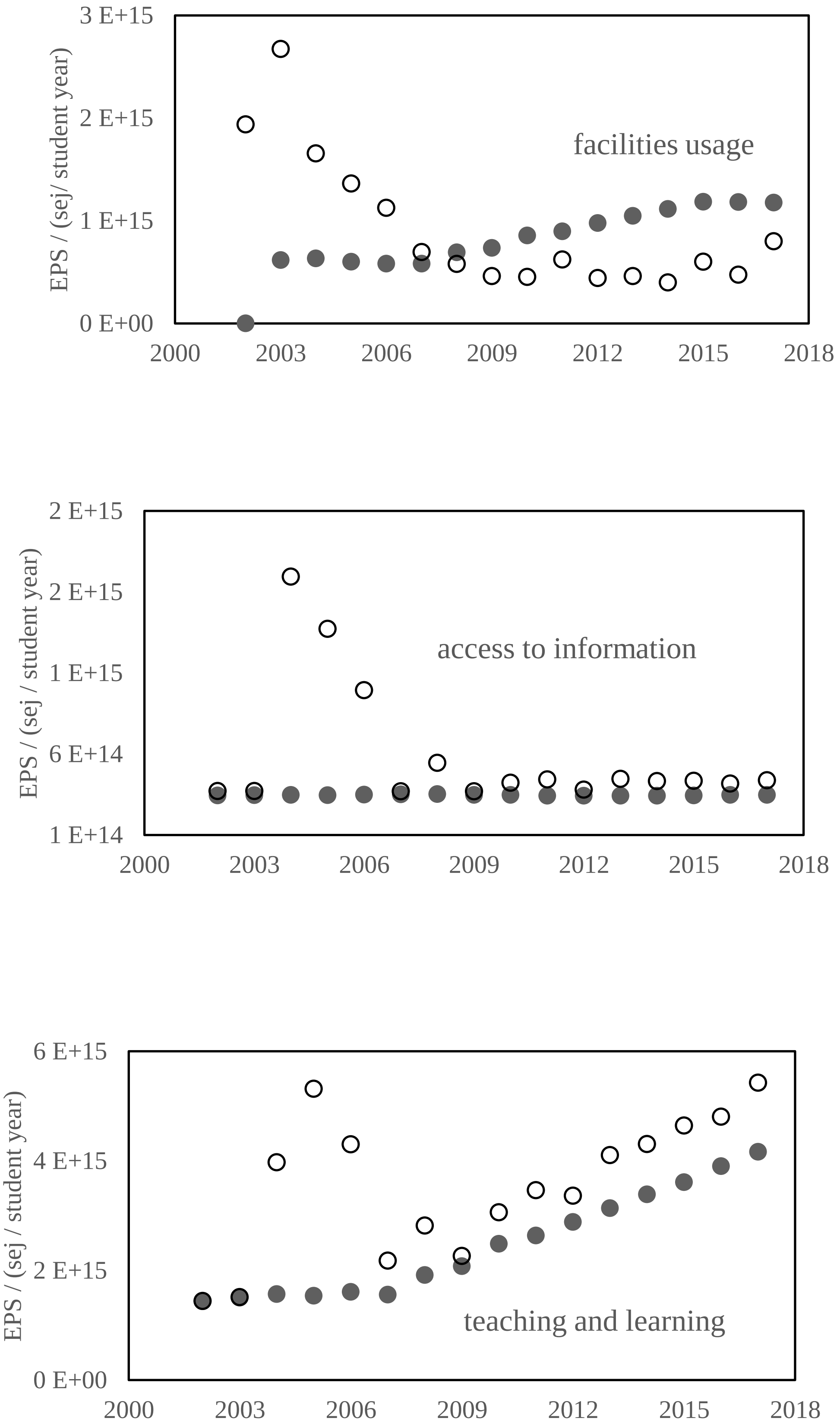


Figure 14 (a, b, c, d). Comparison between the actual EPS and the EPS resulting from a hypothetical full migration from the current mix of traditional and distance teaching modes to distance teaching only.

All charts display the disparity (a “hump” in the chart lines) in EPS ratio numbers that results from the rough approximations of the number of DTCs in operation from 2004 to 2006, calculated from the average number of students per DTC- 173 students per unit- using the numbers published by ABED or INEP. This procedure was deemed necessary due to the non-existence of official reports on the number of DTCs in operation from either institution’s databank. It should be noted that the numbers published by both institutions are conflicting; therefore, the number adopted herein was invariably the highest of the two for a given year.

The EPS in the physical facilities implementation phase of the simulation of a full migration to DT (Fig. 14a) reaches its lowest level in 2014, as a function of a larger number of students sharing the system, whereas the emergy calculated from the actual system configuration exhibits a slow but constant descending behavior, indicating that the number of operating schools is decreasing proportionally faster than the number of attending students. In emergy terms, the migration to DT would benefit from the more simplified DTC structure, in comparison, regardless of the number of attending students.

In Figure 14b, the figures for physical structure usage reflect the fact registered in the main accounting tables, that the emergy required to operate the schools became higher than the emergy required to build the schools, by 2008. The ascending line representing the actual numbers and the drop in the emergy required to operate DTCs give distance teaching the advantage in this question, the lowest rate having been verified in 2014. By 2017, the EPS had acquired an ascending movement, reflecting the constant descend in the number of students and the increase in the UEV of human labor.

Figure 14c illustrates the EPS ratio behavior for the hypothetical situation, where the emergy required for the students to find themselves in the virtual classroom is, invariably, higher than the emergy required for students to commute to physical school campuses. The reason is that one computer unit per student is considered in the calculations in the DT mode and one van is assigned to every group of 16 students. Despite the fact that the emergy of the fuel is higher than the emergy of the electricity used, the UEV for a gram of computer is significantly higher than the UEV for a gram of steel-made vehicles. This simulation makes it clear that, from the emergy perspective, the distance teaching method to access information is a problematic issue in case of a full migration to DT.

Figure 14d shows the higher values obtained for the distance-teaching mode in information flows. This is due to the higher quality of the information from teachers, considering that only teachers with a post-graduation degree are admitted in the system, as, aside from the various possibilities involved, i.e. master and doctorate degrees, a teacher is required to attend training courses to become able to perform pedagogic work via a virtual platform. Although the higher emergy required to feed the teaching and learning activities could be minimized with the use of the work from lower-transformity agents, i.e. teachers, thus improving resource-use efficiency, this panorama could still be considered favorable, since the final purpose of the implementation, usage, and accessing information processes is the teaching and learning process, where the work of higher-transformity teachers is more desirable, from a social point of view.

5.4. Human capital formation via distance teaching

In this section, the aim is to present the resulting emergy demand to form workers under the hypothetical full migration to DT and compare the results from those obtained for the actual scenario. The approximations are based on the previously presented results for the full migration hypothesis. As with section 5.2, the procedure was to redistribute the previously calculated hypothetical total system's emergy into the three-level professional education distribution - primary school, secondary school, and graduation school – based on the percentage of the total students attending each one of these levels (refer to Table 12 for year-by-year distribution). Table 18 contains the emergy that would be required to support a full, uninterrupted education cycle, from 1st grade of primary School to 4th grade of graduation School, from 2002 to 2017 via DT.

Table 18. Hypothetical emergy investment in a full education cycle from 2002 to 2017 via Distance Teaching.

YEAR	Primary School emergy total per year (sej)	Secondary School emergy total per year (sej)	Graduation emergy total per year(sej)
2002	**1.62E+23**	5.06E+22	1.36E+22
2003	**1.94E+23**	6.59E+22	1.84E+22
2004	**3.26E+23**	1.16E+23	3.36E+22
2005	**3.50E+23**	1.41E+23	3.92E+22
2006	**2.77E+23**	1.06E+23	3.36E+22
2007	**1.35E+23**	4.90E+22	1.85E+22
2008	**1.59E+23**	5.91E+22	2.41E+22
2009	**1.29E+23**	4.64E+22	1.99E+22
2010	**1.53E+23**	5.53E+22	2.59E+22
2011	1.76E+23	**6.58E+22**	3.16E+22
2012	1.59E+23	**6.00E+22**	3.02E+22
2013	1.88E+23	**7.13E+22**	3.74E+22
2014	1.90E+23	7.32E+22	**4.09E+22**
2015	2.08E+23	7.87E+22	**4.64E+22**
2016	2.10E+23	7.94E+22	**4.70E+22**
2017	2.47E+23	9.30E+22	**5.71E+22**

The highlighted areas in the chart outline the 2002-2017 education cycle.

The sum of the emergy requirements to support each level during the full education cycle is in Table 19.

Table 19. Hypothetical emergy investment per education level in the full education cycle from 2002 to 2017, via Distance Teaching (sej).

Emergy invested in a full Primary School cycle 2002-2010 (sej)	1.89E+24
Emergy invested in a full Secondary School cycle 2011-2013 (accum. sej)	1.97E+23
Emergy invested in a full Graduation cycle 2014-2017 (accum. sej)*	1.91E+23
Acumulated Emergy by the end of the 2002-2017 cycle	**2.27E+24**

* Considering an average 4-year Graduation program

In table 20, the emergy to form an individual - EPS- via DT, is calculated. As in table 18, a non-linear annual emergy increase pattern is observed.

Table 20. Hypothetical EPS investment in a full education cycle from 2002 to 2017 via Distance Teaching.

YEAR	Primary School EPS total per year (sej/student)	Secondary School EPS total per year (sej/student)	Graduation School EPS total per year (sej/student)
2002	**4.62E+15**	3.88E+15	3.88E+15
2003	**5.64E+15**	4.69E+15	4.69E+15
2004	**9.58E+15**	7.97E+15	7.97E+15
2005	**1.04E+16**	8.59E+15	8.59E+15
2006	**8.34E+15**	6.88E+15	6.88E+15
2007	**4.24E+15**	3.53E+15	3.53E+15
2008	**5.02E+15**	4.15E+15	4.15E+15
2009	**4.06E+15**	3.35E+15	3.35E+15
2010	**4.95E+15**	4.06E+15	4.06E+15
2011	5.77E+15	**4.69E+15**	4.69E+15
2012	5.35E+15	**4.29E+15**	4.29E+15
2013	6.45E+15	**5.12E+15**	5.12E+15
2014	6.66E+15	5.22E+15	**5.22E+15**
2015	7.44E+15	5.78E+15	**5.78E+15**
2016	7.58E+15	5.84E+15	**5.84E+15**
2017	9.03E+15	6.89E+15	**6.89E+15**

Table 21. Hypothetical EPS investment per education level in a full education cycle 2002-2017, except Post-Graduation (sej) via Distance Teaching.

Emergy invested per student in a full Primary School cycle 2002-2010	5.69E+16
Emergy invested per student in a full Secondary School cycle 2011-2013	1.41E+16
Emergy invested per student in a full graduation cycle 2014-2017*	2.37E+16
Acumulated Emergy by the end of the 2002-2017 cycle	**9.47E+16**

* Considering an average 4-year Graduation program

In short, the results point to an increase in the required emergy to support the system in general. Despite several favorable results in the calculations made per phases, such as building/DTC implementation and usage, the DT access to information and teaching and learning demand higher emergy than the traditional system, especially the latter, due to the higher UEV of the teachers' and tutors' work. The effect caused in the emergy supporting the primary school by substituting teachers of varied levels of knowledge for teachers with a post-graduation level, i.e. substituting the existing schools with DT is illustrated in Figures 15 and 16.

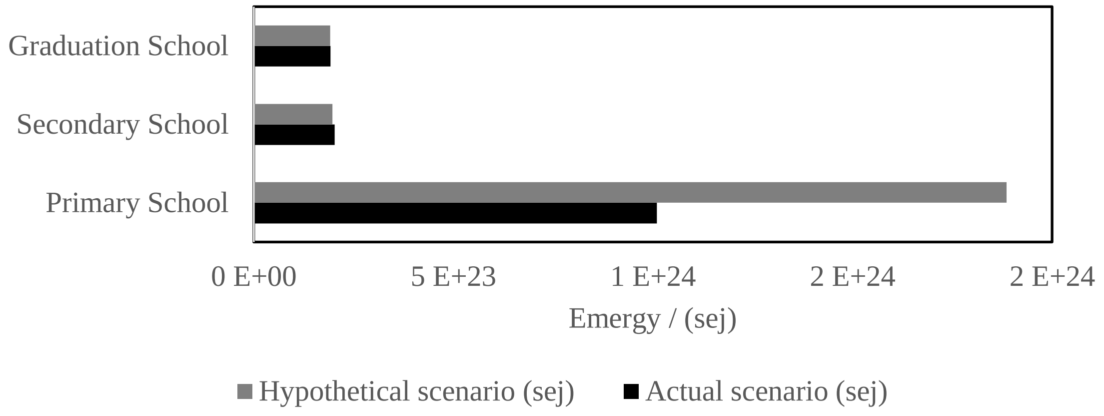


Figure 15. Total emergy invested per level in the education cycle 2002-2017: the actual and the hypothetical scenarios compared.

The comparison between the emergy used to support the actual and the hypothetical scenarios throughout the 2002-2017 cycle illustrate the boost caused over the total emergy by the employment of post-graduated teachers conducting primary school classes, where 70% of all the students in the system aggregate. The difference in emergy requirements to support graduation school is a minimum, since all professors employed are post-graduated, as a prerequisite. In Figure 16, a comparison between the EPS invested in the actual and the hypothetical situation in the cycle is presented.

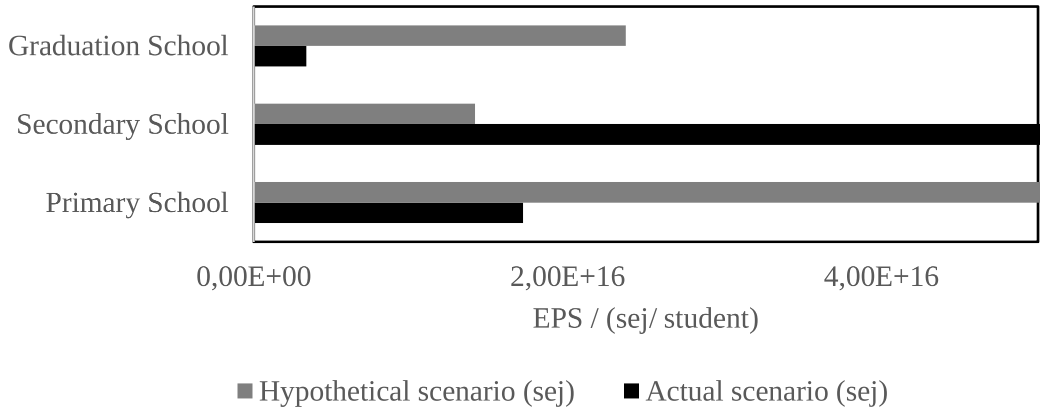


Figure 16. Total EPS invested per level in the education cycle 2002-2017: the actual and the hypothetical scenarios compared.

The EPS comparisons illustrated in Figure 16 reveal that a full DT system has a better performance than the traditional system at secondary level, only. This means more students per sej invested in this sector, whereas in the other levels, the number of students is maintained while the emergy invested is boosted up by the higher UEV of post-graduated teachers. However, the results obtained from comparing the total cost for both modes (Figure 15) do suggest that, from the resource use perspective only, forming workers to foment the national workforce via DT presents itself as a valid alternative, since the driving factor of the differences in the amount of required emergy derive from human labor, which is based on metabolism, rather than from the use of material resources.

5.5.: The Gain-in-Quality Emergy Delivered/ Emergy Invested Ratio

The emergy of work delivered over a given unit time is measured by its quality, which is a function of the UEV. Moreover, the quality of the work delivered results, among other factors, from the time the worker dedicated to attaining his/her highest education level, as a translation for the amount of metabolic energy dispended during the time one spent interacting with the pedagogic resources, in the process of gradually accumulating knowledge, and, consequently, emergy. As soon as a student who formed during the 2002-2017 cycle enrolled in the next higher level cycle, for instance, entering college after graduating from high school, the UEV of the work delivered by this student also leaped to the next level in the energy hierarchy, which expresses the gain in quality achieved. As a result, the final amount of emergy from work delivered over unit time increases. This gain in quality and, consequently, delivery capacity results from an investment made, either public or private. In this sense, the ratio indicator, proposed hereby, of the emergy invested in further education and the amount of emergy of work delivered per unit time can be obtained by applying a simple calculation procedure, to check for the rate progression or otherwise, resulting from the emergy investment in further education. The investment in gain of quality/delivery is i- “positive”, when the ratio for an increment, for example, college education over secondary education, is higher than the previous increment - secondary education over primary education; ii- “null”, in case the ratio is equal to that of the previous increment, and “negative” in case the ratio is lower than the previous one. Either one of these diagnostics is technically possible, since both values – the dividend and the divisor – are dependent on the variables “emergy invested” and “current UEV value for a given level of knowledge”, which, in turn, is dependent on “current population” and the distribution of inhabitants into levels of knowledge. This indicator may also be used to obtain inferences on the education system’s efficiency. Updated ratios can be obtained for comparisons, with every new emergy synthesis of a full 16-year education cycle.

The first step is calculate the emergy delivered per unit time by workers from the three levels – primary, secondary, and graduation. In the estimates, the hypothetical worker’s career will develop into post-2017 years, for which the national population or the national emergy budget, and the UEVs for human labor are still unknown. Thus, the projections will consider the 2017 UEVs, without variation, which also implies considering no alterations in population and national emergy budget. Other points about the typical Brazilian job market policies and practices to be considered, or otherwise, in the calculations of the metabolic energy dispended on work:

- Common labor journeys are mostly configured for 8 hours/day, 5 days/week; in some specific cases (freelancers, shop clerks, etc.), a Saturday morning half-journey – 4 hours- is added. The calculations do consider the most common configuration of 40 hours/week.
- A 30-day vacation applies after every 11 months of service. The vacation periods are subtracted from the total.
- National holydays are not considered.

Therefore, the typical annual labor journey considered in the calculations is 8 hours/day times 230 days/year. Typically, registered workers contribute from 8% to 20% off their wages to social security, depending on the salary range, for 35 years before becoming liable to apply for retirement.

A provisional proportional UEV value for primary and secondary level work was required for these calculations, since the IBGE survey reports the percentage of primary and secondary educational level workers separately. In this sense, considering that primary education occurs during the first 9 of the 12 years of the full basic education cycle (75% of the duration of the cycle), a specific primary level UEV was drawn from multiplying the full basic level UEV – which corresponds to the secondary level UEV- by 0.75.

Additionally, an alternative calculation of the cost to form workers in different levels is provided for the calculation of this and the other indicators, from this point on. The alternative calculation considers the sharing of the emergy of infrastructural items based on the percentage of students belonging to the three levels, and the calculation of the specific emergy of teaching and learning for each one of the three levels separately. The results are on Tables 22 and 23.

Table 22. Total emergy investment in the 2002-2017 cycle - alternative calculation approach

YEAR	Primary School emergy total per year	Secondary school emergy total per year	Graduation School emergy total per year
2002	7.56E+22	9.09E+22	1.46E+22
2003	7.50E+22	9.64E+22	1.62E+22
2004	7.49E+22	1.00E+23	1.75E+22
2005	7.43E+22	1.01E+23	1.59E+22
2006	7.23E+22	1.04E+23	1.73E+22
2007	6.85E+22	9.52E+22	1.75E+22
2008	7.56E+22	1.14E+23	2.13E+22
2009	7.78E+22	1.22E+23	2.27E+22
2010	8.28E+22	1.40E+23	2.78E+22
2011	8.48E+22	1.48E+23	3.10E+22
2012	8.90E+22	1.59E+23	3.42E+22
2013	9.29E+22	1.69E+23	3.81E+22
2014	9.64E+22	1.79E+23	4.28E+22
2015	9.97E+22	1.86E+23	4.64E+22
2016	1.06E+23	2.00E+23	4.86E+22
2017	1.11E+23	2.11E+23	5.23E+22

Table 23. Emergy investment per education level in the full education cycle from 2002 to 2017, except post-graduation – summary.

Emergy invested in a full Primary School cycle 2002-2010 (sej)	6.77E+23
Emergy invested in a full Secondary School cycle 2011-2013 (accum. sej)	4.75E+23
Emergy invested in a full Graduation cycle 2014-2017 (accum. sej)*	1.90E+23
Acumulated Emergy by the end of the 2002-2017 cycle	**1.34E+24**

* Considering an average 4-year Graduation program

The emergy delivered by the worker accumulates throughout his/her career as a function of the time dedicated to work. A new calculation is in order with each UEV update. The calculations are in Table 24.

Table 24. Total emergy delivered over unit time.

Workers' education level	**Labor energy dispended per year per individual (J)**	**Total energy dispended per individual during a 35-year career (J)**	**UEV (2017) per J of work (sej/J)**	**Labor emergy contribution per year (sej)**	**Total emergy contribution per individual at the end of a 35-year career (sej)**
no formal education	9.24E+08	3.23E+10	7.25E+07	6.70E+16	2.35E+18
primary education level	9.24E+08	3.23E+10	8.18E+07	7.56E+16	2.65E+18
secondary education level	9.24E+08	3.23E+10	1.09E+08	1.01E+17	3.53E+18
tertiary education level	9.24E+08	3.23E+10	1.23E+08	1.13E+17	3.97E+18

The results on Table 24 evidence that the workers’ delivered emergy reflects their quality achieved: the emergy delivered by a primary level worker is 13% higher than that by a non-educated worker for the same term; the secondary level worker contributes 33% more emergy, in comparison with the primary-level worker; finally, graduation-level workers contribute 12% more than secondary-level workers and 45% more than primary level workers. These are the dividends used to calculate the cost-productivity ratio of gain in quality.

The divisors are obtained from comparing the difference between the cost in emergy to form a worker in a given level, for example, secondary, with the cost in emergy to form the same worker in the previous (in this case, primary) level. The quotient is herein regarded as the gain-in-quality emergy delivered/emergy invested ratio obtained by secondary and college level workers over primary level ones. In Table 25, a ratio was calculated for each increment, to express the gain in delivery as a function of the gain in quality. The comparison only considers educated workers, due to the inexistence of data required to calculate the emergy of home education of non-formally educated children prior to enrolling in basic school by the year 2002.

Table 25. Gain-in-quality emergy delivered per emergy invested 2017

	From primary to secondary level	**From secondary to graduation level**
Increase in emergy invested in further education	69.8%	16.5%
Increase in emergy delivered per unit time	33%	12%
Gain-in-quality (emergy delivered/emergy invested) ratio (sej)	**0.47/1**	**0.72/1**

The results in Table 25 show that the investment in quality made by the system in forming college level workers over forming secondary level workers in the 2002-2017 education cycle can be considered positive, since an increase in the ratio is observed. The emergy cost to form a graduation-level worker is 16.5% higher than the cost to form a secondary-level worker, whereas the delivery increases 12%, thus an emergy delivered/emergy (for a graduation-level worker) invested ratio increase in ~53% was obtained.

5.6. Emergy invested in education paid back with emergy of delivered work

The emergy of work that is delivered is a contribution to society and its production system, therefore, by delivering work, an individual is also paying back for his/her education.

The following simulation aims to detect how long it takes a worker to deliver an amount emergy of work equal to the amount of emergy invested in his/her education. The simulation refers to students who graduated at some point during the 2002-2017 cycle. The unit chosen to detect the pay-back point is months. The pay-back point can be detected by dividing the emergy invested in formation by the emergy of work delivered per month. In this example, it was assumed that the student joined the active labor force in the immediately following year after graduating from one of the three levels. The emergy contributed results from the metabolic energy dispended/year multiplied by the UEV for the respective worker's level in the year immediately following the worker's graduation in one of the levels. The results are displayed in Table 26.

Table 26. Time required to pay back emergy investment in education with work (in months)

Worker's level	**Accumulated emergy invested in formation (sej/student)**	**Labor emergy contribution per year (sej/yr.worker)***	**Labor time required to pay back investment (months)**
primary education level	1.70E+16	4.73E+16	4.3
secondary education level	5.12E+16	8.16E+16	7.5
graduation education level	8.02E+16	1.13E+17	8.5

(*) Primary education level = 9.24 x 10^8 J/yr * 2011 primary level worker UEV (5.12 x 10^7 sej/J); secondary education level = 9.24 x 10^8 J/yr * 2014 secondary level worker UEV (8.83 x 10^7 sej/J); graduation level = 9.24 x 10^8 J/yr * 2017 graduation worker UEV (1.23 x 10^8 sej/J)

The results in table 26 evidence that the investment in primary education takes the shortest time to pay back. The investment in secondary education takes the longest, due to the amount of emergy invested and the UEV per joule of work delivered. The shorter payback period for the lower level workers, in comparison with higher-level ones, is related to the higher work output per sej invested. All the results are a reflection of the current configuration of the division of the Brazilian population into levels of knowledge, which has a direct influence over their respective UEV values. In all cases, however, a worker’s emergy contribution to the workforce fully covers the emergy invested in his/her full education cycle in less than one year.

5.7. The current workforce emergy delivery potential

The national labor force was composed of 92.1 million individuals in 2017 (IBGE). An estimate of the potential emergy delivery by the workforce is possible, by using the same parameters used in the previous section. However, statistics for workforce division into education levels provided by official organs must be adapted to comply with the separation of emergy UEV by education level, to comply with Odum’s definition of educational category, for UEV calculation purposes (Odum, 1996; p.232). For instance, in the official reports the numbers for incomplete primary level and complete primary level are given separately. The same applies to secondary and college levels. In this sense, for the calculations, both complete and incomplete levels are considered as one distinct level.

The calculations are based on the statistics on workers’ education level for the year 2017, published by the IBGE. Students who completed the first grade of the new 9-year primary level were included in “no instruction” group. Figure 17 is an adaptation of the statistics published by IBGE.

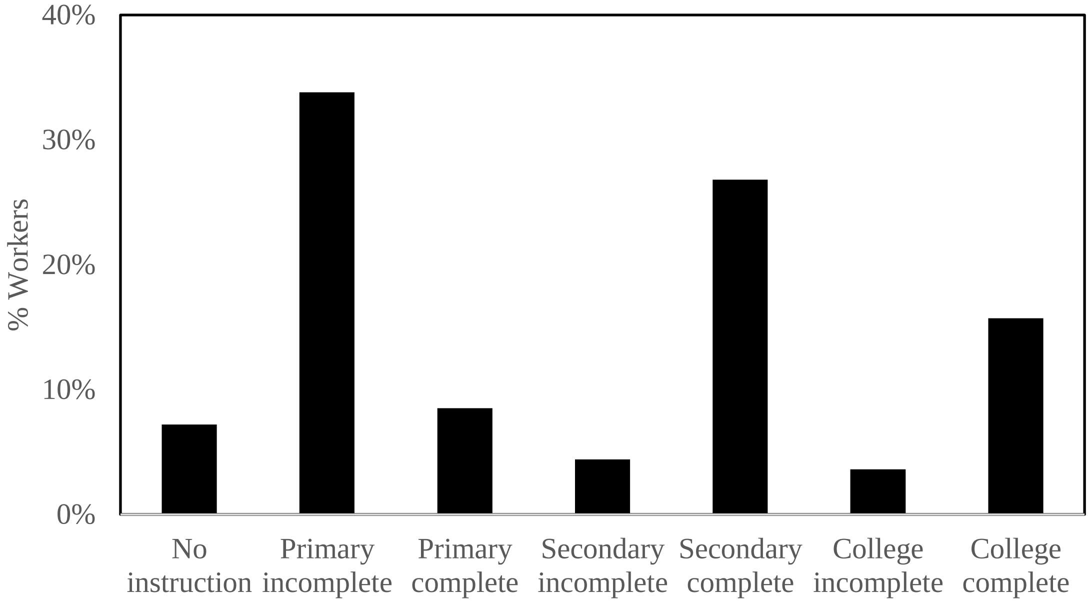
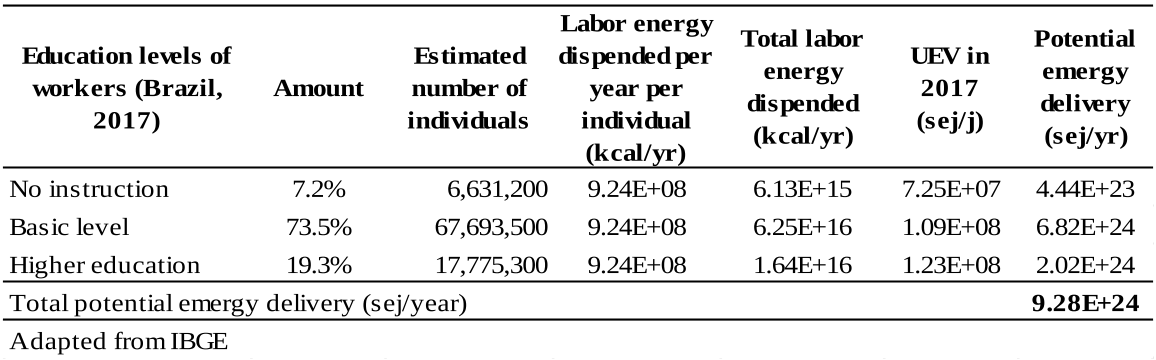


Figure 17. Workers distribution by education level in Brazil (2017)

Source: IBGE (2018).

For these calculations, the primary and secondary levels combine into Basic School level. In emergy terms, therefore, three levels are considered: no instruction, basic school, higher education (college level). Table 27 shows the percentage of workers on each level of education, adapted to comply with the emergy distribution standard and the calculation of the potential annual emergy delivery by the national workforce, using year 2017 data as a reference.

Table 27.Potential emergy delivery by the national workforce in 2017 (sej).



Education levels of workers (Brazil, 2017)	Amount	Estimated number of individuals	Labor energy dispended per year per individual (kcal/yr)	Total labor energy dispended (kcal/yr)	UEV in 2017 (sej/j)	Potential emergy delivery (sej/yr)
No instruction	7.2%	6,631,200	9.24E+08	6.13E+15	7.25E+07	4.44E+23
Basic level	73.5%	67,693,500	9.24E+08	6.25E+16	1.09E+08	6.82E+24
Higher education	19.3%	17,775,300	9.24E+08	1.64E+16	1.23E+08	2.02E+24
Total potential emergy delivery (sej/year)						**9.28E+24**

Adapted from IBGE

The results in table 27 can also be used to establish a cost-benefit ratio in emergy terms. The potential annual emergy delivery in the form of work by the members of the national workforce as a whole can be compared to the annual emergy invested in the educational system. The work from individuals who received formal education amounts to 8.84 x 10^{24} sej (95% of the total) for the year 2017. For that same year, the total verified emergy investment in the education system was 3.74 x 10^{23} sej, which implies that while a given amount of emergy was being invested in the formation of workers, the workforce delivered about 24 times that same amount of emergy. In addition, the emergy of work delivered for the year 2017 by formally educated students alone corresponds to 38% of the total national emergy budget figure for that year.

6. CONCLUSION

In this work, the inputs to the Brazilian education system and its outputs in terms of human capital, i.e. individuals holding different education levels, were analyzed through the emergy synthesis method. The work includes a broad analysis of the rewards to the investment made as the quality of the work performed by the members of the workforce who have obtained some degree of education from the system. The system's viability and outputs under a hypothetical full shift to Distance Teaching was also investigated.

The emergy required to operate the Brazilian education system from 2002 to 2017 increased by 100% in the interim. Results also show that the use of resources to support the system is rapidly rewarded by the emergy of the work delivered by the educated citizen. Such results, however, derive from calculation parameters that include the contributions from all parts directly involved in the system as a whole, rather than the unilateral analysis of the financial resources dispended by the government and private education entrepreneurs, which tend to disregard the students' share of implied financial commitments, in order to attend school. In this sense, it is worth of note that the emergy contribution from students was higher, by one order of magnitude, than the emergy contribution from all other system components during the vast majority of the years of the investigation's timeline. The use of annually updated UEVs for human intellectual work- an attempted approach, given the length of the timeline, with variations in the estimates for the national emergy budget and demographic changes occurring between the starting point and the ending point of the analysis –led students' information-based input to amount to ~50% - ~65% of the total inputs emergy. This corroborates Odum's view that information is a high order input to any system, or a higher order social process, as stated by Campbell (2011). By these results, it becomes evident that most of the emergy required by the system comes from the metabolic energy dispended by the human element in the teaching-learning process and managerial actions, rather than from tangible resources.

The emergy required to educate a worker through a hypothetical 16-year education cycle from 2002 to 2017 in distance teaching mode is 60% higher during the Primary school phase than in the real system, in the same interim, while the total emergy for the DT is higher than the traditional system total emergy by 0 to 25% during the 16-year timeframe. When analyzed by phase, the main drawback lies on the emergy required for students to access information, due to the higher emergy per gram computer, as compared to emergy per gram of the traditional means of transportation to physical campi. Such drawback is largely compensated by the much lower emergy of building construction and maintenance. Additionally, the emergy cost of teaching and learning indicates that although the quality of work delivered by the teachers is pedagogically higher, due to qualification requirements, the higher UEV per joule of work performed by those teachers renders the system less efficient, from an environmental perspective. The difference in EPS between the two modes, however, may be considered as irrelevant. From an environmental perspective, therefore, human capital production via DT can be considered as a viable alternative, since the difference in the total emergy required, in comparison with the traditional system, is, again, based on the higher UEV attributed to metabolic energy-based inputs, rather than on material resources.

The increase in the overall emergy annually invested in the education system occurs, despite the 14% drop in the number of school units in operation and enrolled students in the interim. The still shy adhesion to DT offers a non-significant counterbalance in this sense, with a peak attendance rate barely corresponding to 3% of the total. On the other hand, answering the first research question (“how much invested emergy does the Brazilian education system require to form a worker?”), the emergy required to support the education function in the nation corresponded to 6.5% of the national emergy budget in 2002, dropping to less than 2% in 2017. Albeit intrinsically subject to the constant variations in population and emergy budget-related UEV updates, these numbers are relatively close to the percentage figure from the national GDP invested in education, which is 5.25% in average, considering the numbers from the years 2000 to 2015.

In emergy analyses, the quality of work is measured by the UEV value assigned for the joule of work, in accordance with the worker’s education level. By considering the quantitative reward ratio per level (emergy of work delivered per emergy invested in education), using the year 2017 UEVs as a benchmark, one observes that primary level workers achieve the highest ratio, at 2.8 sej$_{\text{delivered/year}}$/sej$_{\text{invested}}$, followed by secondary level workers, at 1.6 sej$_{\text{delivered/year}}$/sej$_{\text{invested}}$, and college, at 1.4sej$_{\text{delivered/year}}$/sej$_{\text{invested}}$. These last two numbers, although emergy-related, are close to the 1.85 figure published by IPEA as the Brazilian Real (BRL) invested in education versus BRL injected into the GDP growth ratio. However, it must be observed that this parameter of higher efficiency disregards the quality of the work delivered. The analysis of the gain in quality achieved over the previous education level considers the students’ willingness to extend their education cycle to the next higher levels, therefore obtaining a higher UEV per joule of the work they deliver. In this regard, the emergy of the work performed by a college-graduated worker takes the advantage, as he/she will deliver 12% more emergy of work than a secondary level worker, in function of the difference between their respective UEVs, by investing a further 16.5% in emergy, which gives a productivity-per-gain-in-quality ratio of an additional 0.72 sej delivered per sej invested, as opposed to a ratio of 0.47 sej for the secondary-level worker over a primary level one.

In all cases, and as an answer to the second research question put forward ("how long does it take an educated worker to pay back the emergy invested with work?"), the amount of emergy delivered through work equals and surpasses the emergy invested in education before the completion of the workers' first year as a member of the active labor force. This evidences the high reward obtained by the society and the economy for the investment in education.

The conclusive word is, considering the results from the emergy analyses, along with the various indicators obtained from further observations over the results throughout the study, that the Brazilian education system is highly viable, from the perspective of use of resources, providing the society and the economy with highly productive human capital in face of the relatively low emergy investment made.

7. SUGESTIONS FOR FUTURE WORKS

To estimate the emergy invested in the formation and the potential emergy delivery of Brazilian workers, by breaking down the analysis specifically into (a) states and regions, (b) school management jurisdiction, and (c) the primary, secondary and tertiary economic sectors;

to perform a sensitivity analysis for the indicator “gain-in-quality emergy delivered per emergy invested ratio” proposed by and used in this work, by considering the context of different countries and their differences in emergy budget, population, and number of elementary, high school and college graduates.

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9. APPENDIX

Appendix A– Physical school *campi*

A1. Campi implementation

A1.1 Campus model according to PARECER CNE/CEB Nº 8/2010, in m^2.

1-	Classrooms	15	45
2-	Directors' and staff rooms	2	30
3-	Pedagogy staff room	1	30
4-	Teachers' room	1	50
5-	Library and computer lab	1	100
6-	Students' society room	1	45
7-	Computer lab	1	50
8-	Science lab	3	50
9-	Cafeteria	1	80
10-	Kitchen	1	25
11-	Outdoor sports court	1	500
12-	Lavatories	8	20
13-	Deposit room	2	30
14-	TV/Movie room	1	50
15-	Photocopy central	1	15
	Total		2,080

A1.2. Calculation of concrete and steel emergy contribution per year, according to model

Concrete and steel – quantity per room unit

Videoconference room; 50m^2 x 1 unit/campus

Considering 5m (w) x 10m (L) x 3m (h)

Wall 1: 5m x 3m (x 2) = 30m^2

Wall 2: 10m x 3m (x 2) = 60m^2

30m^2 + 60m^2 x 0.2m (thickness) = 18 m^3

Floor = 50 m^2 x 0.25m (thickness) = 12.5 m^3

Slab = 50 m^2 x 0.25m (thickness) = 12.5 m^3

Total 01 room = 43 m^3 reinforced concrete

Concrete density = 2,500 kg/m^3

Total = 43 m^3 x 2,500 kg/m^3 = 1.07 x 10^8 g reinforced concrete

Lifespan = 50 years

Concrete (97%) = (1.07 x 10^8 g x 0,97)/50 = **2.08 x 10^6 g/year**

Steel (3%) = (1.07 x 10^8 g x 0.03)/50 = **6.42 X 10^4 g/year**

Library; 100m^2 x 1 unit/campus

Considering 10m x 10m x 3m

Walls: (4x) 30m^2 = 120m^2 x 0.2m (thickness) = 24m^3

Floor and slab (2x) 100m2 X 0.25m (thickness) = 50m^3

Density of concrete = 2,500 kg/m^3

Total reinforced concrete = $74m^3$ x 2,500 kg/m^3 = 1.86 $x10^8$ g

Lifespan = 50 years

Total = 3.72 x 10^6 g. reinforced concrete/year

Concrete (97%) = **3.61 x 10^6 g/year**

Steel (3%) = **1.12 x 10 ^{4} g/year**

Kitchen/cafeteria: 105m^2 x 1 unit/campus

Considering 10.5m x 10m x 3m

Walls (2 x 31.5m^2) + (2 x 30m^2) x 0.2m (thickness) = 24.6m^3

Floor and slab: (2 x 105m^2) x 0.25m (thickness) = 52.5m^3

Total reinforced concrete = 77.1m^3 X 2,500 kg/m^3 = 1.93 x 10^8 g

Lifespan = 50 years

Total reinforced concrete = 3.86 x 10^6 g/year

Concrete (97%) = **3.74 x 10^6 /year**

Steel (3%) = **1.16 x 10^5 g/year**

Sports court: 500m2 x 1 unit/campus

Considering 20m x 25m x 0.08m^2= 40m^3 of reinforced concrete (floor only)

40m3 x 2,500,000 g/m^3 = 1 x 10^8g of reinforced concrete

Lifespan = 50 years

Reinforced concrete = 1 x 10^8g/50 = 2 x 10^6 g/year

Concrete (97%) = **1.94 x 10^6 g/year**

Steel (3%) = **6 x 10^4 g/year**

Laboratories: 200m^2 each x 1 computer lab and 3 science labs per campus

Considering 10m (w) x 20m (d) x 3m (h)

Walls: (2x 30m^2) + (2x 60m^2) = 180m^2

180m^2 x 0.20m (thickness) = 36m^3

Floor: 200m^2 x 0.25m (thickness) = 50m^3

Slab: 200m^2 x 0.25m (thickness) = 50m^3

Density of concrete = 2,500,000g/m^3

2.500.000g/m^3 X 136m^3 = 3.40 x 10^8g

Lifespan = 50 years

Total reinforced concrete: 3.40 x 10^8g /50 years = 6.80 x 10^6 g/year

Concrete (97%) = **6.60 x 10^6 g/year**

Steel (3%) = **2.04 x 10^5 g/year**

Photocopy central (15m^2) + warehouses (2 x 30m^2) (combined) x 1 unit per campus

Considering 10m (w) x 7.5m (d) x 3m (h)

Walls: (2x 30m^2) + (2x 22.5m^2) = 105m^2 x 0.2m (thickness) = 21m^3

Floor: 75m^2 x 0.25m (thickness) = 18.8m^3

Slab: 75m^2 x 0.25m (thickness) = 18.8m^3

Total: 58.6m^3 x 2.500.000g/m^3 (density) =1.47 x 10^8 g of reinforced concrete

1.47 x 10^8 g / 50 years (lifespan) = 2.94 x 10^6 g/year

Concrete (97%) = **2.85 x 10^6 g/year**

Steel (3%) = **8.82 x 10^4 g/year**

Restrooms: 20m^2 each x 8 units per campus

Considering 5m (w) x 4m (d) x 3m (h)

Walls: (2 x 15m^2) + (2 x 12m^2) x 0.2m (thickness) = 10.8m^3 reinforced concrete

Floor: $20m^2$ x 0.25m = $5m^3$

Slab: $20m^2$ x 0.25m = $5m^3$

Total reinforced concrete: $20.8m^3$ x 2,500,000g/m^3 = 5.20 x 10^7 g

5.20 x 10^7 g /50 years (lifespan) = 1.04 x 10^6 g/year

Concrete (97%) = **1.01 x 10^6 g/year**

Steel (3%) = **3.12 x 10^4 g/year**

Administration and pedagogic coordination room: ($60m^2$) x 02 units per campus

Considering 6m (w) x 10m (d) x 3m (h)

Walls: (2 x $18m^2$) + (2 x $30m^2$) x 0.2m (thickness) = 19.2 m^3 of reinforced concrete

Floor: 60 m^2 x 0.25m (thickness) = 15 m^3

Slab: 60 m^2 x 0.25m (thickness) = 15 m^3

Total reinforced concrete: $49.2m^3$ x 2,500,000 g/m^3 = 1.23 x 10^8 g

Concrete (97%) = 1.23 x 10^8 g/ 50 years (lifespan) x 97% = **2.39 x 10^6 g/year**

Steel (3%) = 2.46 x 10^6 g x 3% = **7.38 x 10^4 g/year**

Students Association room: $45m^2$ x 01 unit per campus

Considering 9m (d) x 5m (w) x 3m (h)

Walls: (2 x $27m^2$) + (2 x $15m^2$) x 0.2m (thickness) = $16.8m^3$ of reinforced concrete

Floor: $45m^2$ x 0.25m (thickness) = 11.3 m^3

Slab: $45m^2$ x 0.25m (thickness) = 11.3 m^3

Total reinforced concrete: 39.4 m^3 (reinf. concrete) x 2,500,000 g/m^3 (density of concrete) = 9.85 x 10^7 g

Lifespan = 50 years

Concrete (97%) = (9.85 x 10^7 g/50 years) x 97% = **1.91 x 10^6 g/year**

Steel (3%) = (9.85 x 10^7 g/50 years) x 3% = **5.91 x 10^4 g/year**

Classrooms: $45m^2$ each x 15 units per campus

Considering 9m (d) x 5m (w) x 3m (h)

Walls: (2 x $27m^2$) + (2 x $15m^2$) x 0.2m (thickness) = $16.8m^3$ of reinforced concrete

Floor: $45m^2$ x 0.25m (thickness) = 11.3 m^3

Slab: $45m^2$ x 0.25m (thickness) = 11.3 m^3

Total reinforced concrete: 39.4 m^3 (reinf. concrete) x 2,500,000 g/m^3 (density of concrete) = 9.85 x 10^7 g

Lifespan = 50 years

Concrete (97%) = (9.85 x 10^7 g/50 years) x 97% = **1.91 x 10^6 g/year**

Steel (3%) = (9.85 x 10^7 g/50 years) x 3% = **5.91 x 10^4 g/year**

Teachers' room: $50m^2$ x 01 unit per campus

Considering 5m (w) x 10m (L) x 3m (h)

Wall 1: 5m x 3m (x 2) = $30m^2$

Wall 2: 10m x 3m (x 2) = $60m^2$

$30m^2$ + $60m^2$ x 0.2m (thickness) = 18 m^3

Floor = 50 m^2 x 0.25m (thickness) = 12.5 m^3

Slab = 50 m^2 x 0.25m (thickness) = 12.5 m^3

Total 01 room = 43 m^3 reinforced concrete

Concrete density = 2,500 kg/m^3

Total = 43 m^3 x 2,500 kg/m^3 = 1.07 x 10^8 g reinforced concrete

Lifespan = 50 years

Concrete (97%) = (1.07 x 10^8 g x 0,97)/50 = **2.08 x 10^6 g/year**

Steel (3%) = (1.07 x 10^8 g x 0.03)/50 = **6.42 X 10^4 g/year**

Total reinforced concrete per unit/year (considering lifespan = 50 years) = 6.63 x 10^7 g

Total concrete and steel, considering 97% concrete and 3% steel.

School campi buildings - Total concrete and steel				
Year	**Institutions**	**Reinf. Concrete (g)**	**Concrete (g)**	**Steel (g)**
2002	214,188	1.42E+13	1.38E+13	4.25E+11
2003	211,933	1.40E+13	1.36E+13	4.21E+11
2004	210,094	1.39E+13	1.35E+13	4.17E+11
2005	207,234	1.37E+13	1.33E+13	4.11E+11
2006	203,973	1.35E+13	1.31E+13	4.05E+11
2007	198,397	1.31E+13	1.27E+13	3.94E+11
2008	199,761	1.32E+13	1.28E+13	3.97E+11
2009	197,468	1.31E+13	1.27E+13	3.92E+11
2010	194,939	1.29E+13	1.25E+13	3.87E+11
2011	193,047	1.28E+13	1.24E+13	3.83E+11
2012	192,676	1.28E+13	1.24E+13	3.83E+11
2013	190,706	1.26E+13	1.22E+13	3.79E+11
2014	188,673	1.25E+13	1.21E+13	3.75E+11
2015	186,441	1.23E+13	1.20E+13	3.70E+11
2016	186,081	1.23E+13	1.19E+13	3.69E+11
2017	184,145	1.22E+13	1.18E+13	3.66E+11

A1.3. Computers

Computers for staff use, considering 8 units/school in 95% of schools:

Year	Institutions	Computers for staff use (95% of schools x 8 units each)	Mass (CPU, monitor, keyboard, mouse, printer) (g)	Total (g)	(g) in one year (lifespan = 5 years)
2002	214,188	1627829	21250	**3.46E+10**	**6.92E+09**
2003	211,933	1610691	21250	**3.42E+10**	**6.85E+09**
2004	210,094	1596714	21250	**3.39E+10**	**6.79E+09**
2005	207,234	1574978	21250	**3.35E+10**	**6.69E+09**
2006	203,973	1550195	21250	**3.29E+10**	**6.59E+09**
2007	198,397	1507817	21250	**3.20E+10**	**6.41E+09**
2008	199,761	1518184	21250	**3.23E+10**	**6.45E+09**
2009	197,468	1500757	21250	**3.19E+10**	**6.38E+09**
2010	194,939	1481536	21250	**3.15E+10**	**6.30E+09**
2011	193,047	1467157	21250	**3.12E+10**	**6.24E+09**
2012	192,676	1464338	21250	**3.11E+10**	**6.22E+09**
2013	190,706	1449366	21250	**3.08E+10**	**6.16E+09**
2014	188,673	1433915	21250	**3.05E+10**	**6.09E+09**
2015	186,441	1416952	21250	**3.01E+10**	**6.02E+09**
2016	186,081	1414216	21250	**3.01E+10**	**6.01E+09**
2017	184,145	1399502	21250	**2.97E+10**	**5.95E+09**

Computers for students use, considering 31 units/school in 90% of schools:

Year	Institutions	Computers for students use (90% of schools x 31 units each)	Mass (CPU, monitor, keyboard, mouse, printer) (g)	Total (g)	(g) in one year (lifespan = 5 years)
2002	214,188	5975845	16400	**9.80E+10**	**1.96E+10**
2003	211,933	5912931	16400	**9.70E+10**	**1.94E+10**
2004	210,094	5861623	16400	**9.61E+10**	**1.92E+10**
2005	207,234	5781829	16400	**9.48E+10**	**1.90E+10**
2006	203,973	5690847	16400	**9.33E+10**	**1.87E+10**
2007	198,397	5535276	16400	**9.08E+10**	**1.82E+10**
2008	199,761	5573332	16400	**9.14E+10**	**1.83E+10**
2009	197,468	5509357	16400	**9.04E+10**	**1.81E+10**
2010	194,939	5438798	16400	**8.92E+10**	**1.78E+10**
2011	193,047	5386011	16400	**8.83E+10**	**1.77E+10**
2012	192,676	5375660	16400	**8.82E+10**	**1.76E+10**
2013	190,706	5320697	16400	**8.73E+10**	**1.75E+10**
2014	188,673	5263977	16400	**8.63E+10**	**1.73E+10**
2015	186,441	5201704	16400	**8.53E+10**	**1.71E+10**
2016	186,081	5191660	16400	**8.51E+10**	**1.70E+10**
2017	184,145	5137646	16400	**8.43E+10**	**1.69E+10**

A2. Campus usage

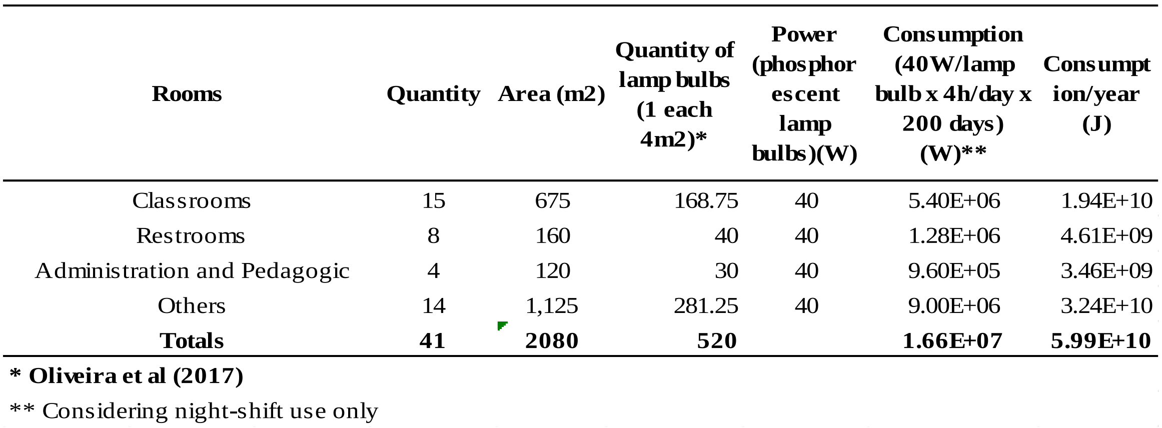
A2.1. Electricity

Electricity consumption per campus/school year

1 W= 1 J/sec

Calculus: no. of lamp bulbs x 40W x hours/day x days/year x 3600 J

Lamp bulbs:



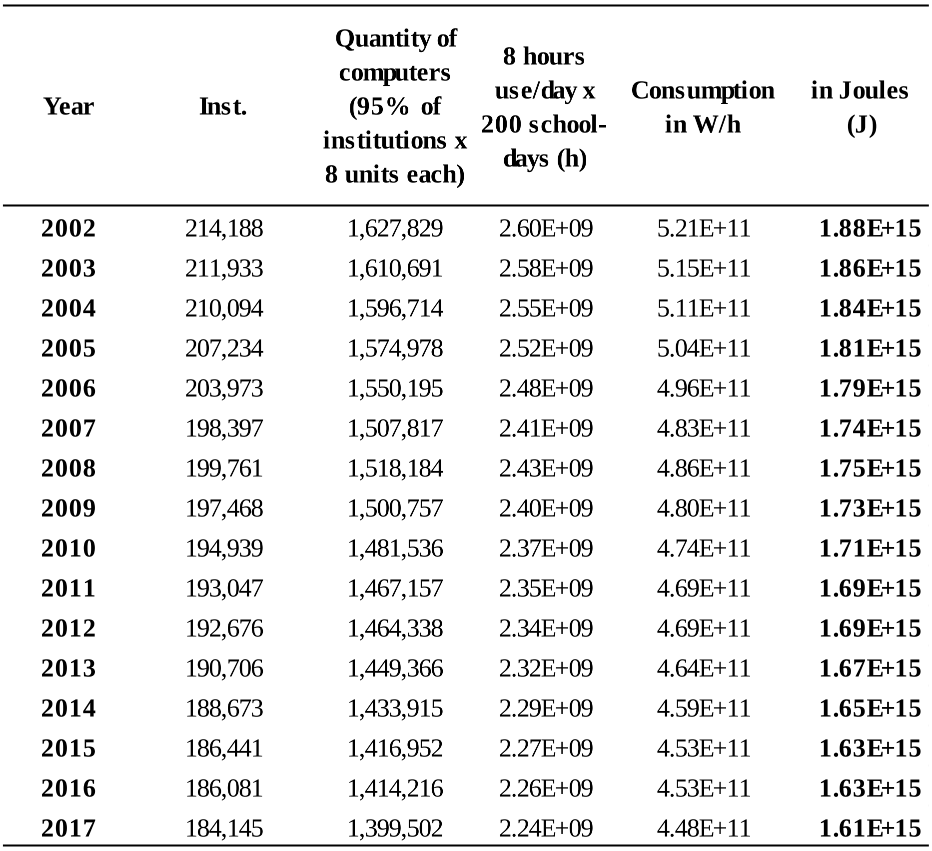
Rooms	Quantity	Area (m2)	Quantity of lamp bulbs (1 each 4m2)*	Power (phosphorescent lamp bulbs)(W)	Consumption (40W/lamp bulb x 4h/day x 200 days) (W)**	Consumption/year (J)
Classrooms	15	675	168.75	40	5.40E+06	1.94E+10
Restrooms	8	160	40	40	1.28E+06	4.61E+09
Administration and Pedagogic	4	120	30	40	9.60E+05	3.46E+09
Others	14	1,125	281.25	40	9.00E+06	3.24E+10
Totals	**41**	**2080**	**520**		**1.66E+07**	**5.99E+10**

*** Oliveira et al (2017)**

** Considering night-shift use only

Electricity consumption from computer use by staff

Considering nominal power consumption = 200 W



Year	Inst.	Quantity of computers (95% of institutions x 8 units each)	8 hours use/day x 200 school-days (h)	Consumption in W/h	in Joules (J)
2002	214,188	1,627,829	2.60E+09	5.21E+11	**1.88E+15**
2003	211,933	1,610,691	2.58E+09	5.15E+11	**1.86E+15**
2004	210,094	1,596,714	2.55E+09	5.11E+11	**1.84E+15**
2005	207,234	1,574,978	2.52E+09	5.04E+11	**1.81E+15**
2006	203,973	1,550,195	2.48E+09	4.96E+11	**1.79E+15**
2007	198,397	1,507,817	2.41E+09	4.83E+11	**1.74E+15**
2008	199,761	1,518,184	2.43E+09	4.86E+11	**1.75E+15**
2009	197,468	1,500,757	2.40E+09	4.80E+11	**1.73E+15**
2010	194,939	1,481,536	2.37E+09	4.74E+11	**1.71E+15**
2011	193,047	1,467,157	2.35E+09	4.69E+11	**1.69E+15**
2012	192,676	1,464,338	2.34E+09	4.69E+11	**1.69E+15**
2013	190,706	1,449,366	2.32E+09	4.64E+11	**1.67E+15**
2014	188,673	1,433,915	2.29E+09	4.59E+11	**1.65E+15**
2015	186,441	1,416,952	2.27E+09	4.53E+11	**1.63E+15**
2016	186,081	1,414,216	2.26E+09	4.53E+11	**1.63E+15**
2017	184,145	1,399,502	2.24E+09	4.48E+11	**1.61E+15**

Electricity consumption from computer use by students

Considering nominal power consumption = 200W

Year	Inst.	(90% of insti	2 hours use/day x 200 school days	Consumption in W/h	in Joules (J)
2002	214,188	5,975,845	2.39E+09	4.78E+11	**1.72E+15**
2003	211,933	5,912,931	2.37E+09	4.73E+11	**1.70E+15**
2004	210,094	5,861,623	2.34E+09	4.69E+11	**1.69E+15**
2005	207,234	5,781,829	2.31E+09	4.63E+11	**1.67E+15**
2006	203,973	5,690,847	2.28E+09	4.55E+11	**1.64E+15**
2007	198,397	5,535,276	2.21E+09	4.43E+11	**1.59E+15**
2008	199,761	5,573,332	2.23E+09	4.46E+11	**1.61E+15**
2009	197,468	5,509,357	2.20E+09	4.41E+11	**1.59E+15**
2010	194,939	5,438,798	2.18E+09	4.35E+11	**1.57E+15**
2011	193,047	5,386,011	2.15E+09	4.31E+11	**1.55E+15**
2012	192,676	5,375,660	2.15E+09	4.30E+11	**1.55E+15**
2013	190,706	5,320,697	2.13E+09	4.26E+11	**1.53E+15**
2014	188,673	5,263,977	2.11E+09	4.21E+11	**1.52E+15**
2015	186,441	5,201,704	2.08E+09	4.16E+11	**1.50E+15**
2016	186,081	5,191,660	2.08E+09	4.15E+11	**1.50E+15**
2017	184,145	5,137,646	2.06E+09	4.11E+11	**1.48E+15**

A2.2. Workbooks (including Distance Teaching)

Considering 8 books/student/year for basic school, and 4 books/student/year for higher education

Total books used per year:

Year	Primary school students	books per year	Secondary school students	books per year	Youth and aduts program	books per year
2002	35,150,362	281,202,896	8,710,584	69,684,672	3,779,593	30,236,744
2003	34,438,749	275,509,992	9,072,942	72,583,536	4,403,436	35,227,488
2004	34,012,434	272,099,472	9,169,357	73,354,856	4,577,268	36,618,144
2005	33,534,561	268,276,488	9,031,302	72,250,416	5,615,409	44,923,272
2006	33,282,663	266,261,304	8,906,820	71,254,560	5,616,291	44,930,328
2007	31,733,198	253,865,584	8,264,816	66,118,528	4,940,165	39,521,320
2008	31,694,497	253,555,976	8,272,159	66,177,272	4,902,374	39,218,992
2009	31,705,528	253,644,224	8,337,160	66,697,280	4,661,332	37,290,656
2010	31,005,341	248,042,728	8,357,675	66,861,400	4,287,234	34,297,872
2011	30,490,476	243,923,808	8,401,829	67,214,632	4,082,528	32,660,224
2012	29,826,627	238,613,016	8,377,942	67,023,536	3,961,925	31,695,400
2013	29,187,602	233,500,816	8,314,048	66,512,384	3,830,207	30,641,656
2014	28,571,512	228,572,096	8,301,380	66,411,040	3,653,530	29,228,240
2015	27,931,210	223,449,680	8,076,150	64,609,200	3,491,869	27,934,952
2016	27,691,478	221,531,824	8,133,040	65,064,320	3,482,174	27,857,392
2017	27,348,080	218,784,640	7,930,384	63,443,072	3,598,716	28,789,728

Vocational school students	books per year	Higher education students	books per year	Total books per year
565,042	4,520,336	3,479,913	13,919,652	**399,564,300**
589,383	4,715,064	3,887,022	15,548,088	**403,584,168**
676,093	5,408,744	4,163,733	16,654,932	**404,136,148**
707,263	5,658,104	4,453,156	17,812,624	**408,920,904**
744,690	5,957,520	4,676,646	18,706,584	**407,110,296**
682,431	5,459,448	4,880,381	19,521,524	**384,486,404**
790,142	6,321,136	5,080,056	20,320,224	**385,593,600**
861,114	6,888,912	5,115,896	20,463,584	**384,984,656**
924,670	7,397,360	5,449,120	21,796,480	**378,395,840**
1,483,643	11,869,144	5,746,762	22,987,048	**378,654,856**
1,605,608	12,844,864	5,923,838	23,695,352	**373,872,168**
1,667,685	13,341,480	6,152,405	24,609,620	**368,605,956**
1,945,006	15,560,048	6,486,171	25,944,684	**365,716,108**
1,917,192	15,337,536	6,633,545	26,534,180	**357,865,548**
1,859,940	14,879,520	6,554,283	26,217,132	**355,550,188**
1,831,003	14,648,024	6,529,681	26,118,724	**351,784,188**

Energy of books

Energy of books (g) = number of books x 250g (unit)/20 years (lifespan)

Energy of books (J) = number of books x 250g (unit)/20 years (lifespan) x 14500 J (Campbell & Cai, 2007)

Year	Primary	books/year	Energy of books (g)	Energy of books (J)	Youth and adults program	books/year	Energy of books (g)	Energy of books (J)
2002	35,150,362	281,202,896	3.52E+09	**5.10E+13**	3,779,593	30,236,744	3.78E+08	**5.48E+12**
2003	34,438,749	275,509,992	3.44E+09	**4.99E+13**	4,403,436	35,227,488	4.40E+08	**6.38E+12**
2004	34,012,434	272,099,472	3.40E+09	**4.93E+13**	4,577,268	36,618,144	4.58E+08	**6.64E+12**
2005	33,534,561	268,276,488	3.35E+09	**4.86E+13**	5,615,409	44,923,272	5.62E+08	**8.14E+12**
2006	33,282,663	266,261,304	3.33E+09	**4.83E+13**	5,616,291	44,930,328	5.62E+08	**8.14E+12**
2007	31,733,198	253,865,584	3.17E+09	**4.60E+13**	4,940,165	39,521,320	4.94E+08	**7.16E+12**
2008	31,694,497	253,555,976	3.17E+09	**4.60E+13**	4,902,374	39,218,992	4.90E+08	**7.11E+12**
2009	31,705,528	253,644,224	3.17E+09	**4.60E+13**	4,661,332	37,290,656	4.66E+08	**6.76E+12**
2010	31,005,341	248,042,728	3.10E+09	**4.50E+13**	4,287,234	34,297,872	4.29E+08	**6.22E+12**
2011	30,490,476	243,923,808	3.05E+09	**4.42E+13**	4,082,528	32,660,224	4.08E+08	**5.92E+12**
2012	29,826,627	238,613,016	2.98E+09	**4.32E+13**	3,961,925	31,695,400	3.96E+08	**5.74E+12**
2013	29,187,602	233,500,816	2.92E+09	**4.23E+13**	3,830,207	30,641,656	3.83E+08	**5.55E+12**
2014	28,571,512	228,572,096	2.86E+09	**4.14E+13**	3,653,530	29,228,240	3.65E+08	**5.30E+12**
2015	27,931,210	223,449,680	2.79E+09	**4.05E+13**	3,491,869	27,934,952	3.49E+08	**5.06E+12**
2016	27,691,478	221,531,824	2.77E+09	**4.02E+13**	3,482,174	27,857,392	3.48E+08	**5.05E+12**
2017	27,348,080	218,784,640	2.73E+09	**3.97E+13**	3,598,716	28,789,728	3.60E+08	**5.22E+12**

Year	Secondary	Books/year	Energy of books (g)	Energy of books (J)	Vocational	Books/year	Energy of books (g)	Energy of books (J)	Higher Education	Books/year	Energy of books (g)	Energy of books (J)
2002	8,710,584	69,684,672	8.71E+08	**1.26E+13**	565,042	4,520,336	5.65E+07	**8.19E+11**	3,479,913	13,919,652	1.74E+08	**2.52E+12**
2003	9,072,942	72,583,536	9.07E+08	**1.32E+13**	589,383	4,715,064	5.89E+07	**8.55E+11**	3,887,022	15,548,088	1.94E+08	**2.82E+12**
2004	9,169,357	73,354,856	9.17E+08	**1.33E+13**	676,093	5,408,744	6.76E+07	**9.80E+11**	4,163,733	16,654,932	2.08E+08	**3.02E+12**
2005	9,031,302	72,250,416	9.03E+08	**1.31E+13**	707,263	5,658,104	7.07E+07	**1.03E+12**	4,453,156	17,812,624	2.23E+08	**3.23E+12**
2006	8,906,820	71,254,560	8.91E+08	**1.29E+13**	744,690	5,957,520	7.45E+07	**1.08E+12**	4,676,646	18,706,584	2.34E+08	**3.39E+12**
2007	8,264,816	66,118,528	8.26E+08	**1.20E+13**	682,431	5,459,448	6.82E+07	**9.90E+11**	4,880,381	19,521,524	2.44E+08	**3.54E+12**
2008	8,272,159	66,177,272	8.27E+08	**1.20E+13**	790,142	6,321,136	7.90E+07	**1.15E+12**	5,080,056	20,320,224	2.54E+08	**3.68E+12**
2009	8,337,160	66,697,280	8.34E+08	**1.21E+13**	861,114	6,888,912	8.61E+07	**1.25E+12**	5,115,896	20,463,584	2.56E+08	**3.71E+12**
2010	8,357,675	66,861,400	8.36E+08	**1.21E+13**	924,670	7,397,360	9.25E+07	**1.34E+12**	5,449,120	21,796,480	2.72E+08	**3.95E+12**
2011	8,401,829	67,214,632	8.40E+08	**1.22E+13**	1,483,643	11,869,144	1.48E+08	**2.15E+12**	5,746,762	22,987,048	2.87E+08	**4.17E+12**
2012	8,377,942	67,023,536	8.38E+08	**1.21E+13**	1,605,608	12,844,864	1.61E+08	**2.33E+12**	5,923,838	23,695,352	2.96E+08	**4.29E+12**
2013	8,314,048	66,512,384	8.31E+08	**1.21E+13**	1,667,685	13,341,480	1.67E+08	**2.42E+12**	6,152,405	24,609,620	3.08E+08	**4.46E+12**
2014	8,301,380	66,411,040	8.30E+08	**1.20E+13**	1,945,006	15,560,048	1.95E+08	**2.82E+12**	6,486,171	25,944,684	3.24E+08	**4.70E+12**
2015	8,076,150	64,609,200	8.08E+08	**1.17E+13**	1,917,192	15,337,536	1.92E+08	**2.78E+12**	6,633,545	26,534,180	3.32E+08	**4.81E+12**
2016	8,133,040	65,064,320	8.13E+08	**1.18E+13**	1,859,940	14,879,520	1.86E+08	**2.70E+12**	6,554,283	26,217,132	3.28E+08	**4.75E+12**
2017	7,930,384	63,443,072	7.93E+08	**1.15E+13**	1,831,003	14,648,024	1.83E+08	**2.65E+12**	6,529,681	26,118,724	3.26E+08	**4.73E+12**

A2.3. Labor (staff)

School Management Personnel	
School principals (titular and vice)	2
Secretariat	4
Maintenance and Infrastructure (primary-level employee)	4
Maintenance and Infrastructure (secondary-level employee)	4
Pedagogy coordinators	2
Librarian	2

Calculation of the staff metabolic energy (considering 120 kcal/hour consumption)

Year	Institutions	No. of Basic Level-staff members*	Workers' metabolic energy**	No. of Mid Level-staff members*	Workers' metabolic energy**	No. of Higher Level-staff members*	Workers' metabolic energy**	Total staff energy
2002	214,188	856,752	6.89E+14	856,752	6.89E+14	1,713,504	1.38E+15	**2.75E+15**
2003	211,933	847,732	6.81E+14	847,732	6.81E+14	1,695,464	1.36E+15	**2.73E+15**
2004	210,094	840,376	6.75E+14	840,376	6.75E+14	1,680,752	1.35E+15	**2.70E+15**
2005	207,234	828,936	6.66E+14	828,936	6.66E+14	1,657,872	1.33E+15	**2.66E+15**
2006	203,973	815,892	6.56E+14	815,892	6.56E+14	1,631,784	1.31E+15	**2.62E+15**
2007	198,397	793,588	6.38E+14	793,588	6.38E+14	1,587,176	1.28E+15	**2.55E+15**
2008	199,761	799,044	6.42E+14	799,044	6.42E+14	1,598,088	1.28E+15	**2.57E+15**
2009	197,468	789,872	6.35E+14	789,872	6.35E+14	1,579,744	1.27E+15	**2.54E+15**
2010	194,939	779,756	6.27E+14	779,756	6.27E+14	1,559,512	1.25E+15	**2.51E+15**
2011	193,047	772,188	6.21E+14	772,188	6.21E+14	1,544,376	1.24E+15	**2.48E+15**
2012	192,676	770,704	6.19E+14	770,704	6.19E+14	1,541,408	1.24E+15	**2.48E+15**
2013	190,706	762,824	6.13E+14	762,824	6.13E+14	1,525,648	1.23E+15	**2.45E+15**
2014	188,673	754,692	6.07E+14	754,692	6.07E+14	1,509,384	1.21E+15	**2.43E+15**
2015	186,441	745,764	5.99E+14	745,764	5.99E+14	1,491,528	1.20E+15	**2.40E+15**
2016	186,081	744,324	5.98E+14	744,324	5.98E+14	1,488,648	1.20E+15	**2.39E+15**
2017	184,145	736,580	5.92E+14	736,580	5.92E+14	1,473,160	1.18E+15	**2.37E+15**

*Considering the staff and job assignments as described in CNE-CEB/08

** Considering a daily 8-hour 5 days/week workload

A2.4. Human Labor UEVs for Brazil from 2002 to 2017

Indicators calculated in this work

Table of UEVs for human labor (unrelated to information transfer) from 2002 to 2017.

Year	Total National Emergy (U)	Final Population Figure for the year	Full population energy (J)	Average per individual UEV (sej/J)
2002	2.77E+24	1.78E+08	6.79E+17	4.08E+06
2003	3.80E+24	1.80E+08	6.88E+17	5.53E+06
2004	4.80E+24	1.82E+08	6.96E+17	6.89E+06
2005	5.70E+24	1.84E+08	7.05E+17	8.09E+06
2006	6.40E+24	1.87E+08	7.13E+17	8.98E+06
2007	7.74E+24	1.89E+08	7.21E+17	1.07E+07
2008	9.00E+24	1.91E+08	7.30E+17	1.23E+07
2009	1.06E+25	1.93E+08	7.38E+17	1.44E+07
2010	1.28E+25	1.95E+08	7.47E+17	1.71E+07
2011	1.39E+25	1.98E+08	7.55E+17	1.84E+07
2012	1.54E+25	2.00E+08	7.63E+17	2.02E+07
2013	1.70E+25	2.02E+08	7.73E+17	2.20E+07
2014	1.86E+25	2.04E+08	7.80E+17	2.38E+07
2015	2.00E+25	2.06E+08	7.87E+17	2.54E+07
2016	2.18E+25	2.07E+08	7.91E+17	2.76E+07
2017	2.34E+25	2.08E+08	7.95E+17	2.95E+07
2018	2.5E+25	2.09E+08	7.98E+17	3.13E+07

Total National Emergy for the years 2002, 2004, 2007, 2008 and 2011 extracted from Giannetti et al, 2017. The values for the gaps are assumptions made in this work by interpolating the known values.

Population energy based on a 2,500 kcal/day diet. Total energy = 2,500 kcal/day x 4186 j/kcal x 365 days/year x number of inhabitants.

A3. Access to Information

A3.1. Transportation (in-class students)

Mass of vans: calculated as the gross weight in steel per unit x number of units /12 (years lifespan)

Considering all students transported by a 4,000 kilogram van

YEAR	Students	*van (16 seats) units	Mass (units x 4,000,000 g)	Total/year (lifespan = 12 years - PL 5585/16) (g)
2002	58,423,667	3,651,479	1.46E+13	1.22E+12
2003	59,383,355	3,711,460	1.48E+13	1.24E+12
2004	59,502,647	3,718,915	1.49E+13	1.24E+12
2005	60,546,704	3,784,169	1.51E+13	1.26E+12
2006	60,618,693	3,788,668	1.52E+13	1.26E+12
2007	57,909,309	3,619,332	1.45E+13	1.21E+12
2008	58,312,924	3,644,558	1.46E+13	1.21E+12
2009	57,696,348	3,606,022	1.44E+13	1.20E+12
2010	56,999,009	3,562,438	1.42E+13	1.19E+12
2011	56,719,381	3,544,961	1.42E+13	1.18E+12
2012	56,468,888	3,529,306	1.41E+13	1.18E+12
2013	56,194,853	3,512,178	1.40E+13	1.17E+12
2014	56,257,542	3,516,096	1.41E+13	1.17E+12
2015	55,430,057	3,464,379	1.39E+13	1.15E+12
2016	55,991,019	3,499,439	1.40E+13	1.17E+12
2017	55,746,595	3,484,162	1.39E+13	1.16E+12

A3.2. Fuel consumption (in-class students)

Diesel energy

*Considering 10 Km/liter x 60 Km/day x 200 days/year
**Considering 8,620 Kcal/Kg x 4,186 J/Kcal

Year	Students (total)	Number of 16-seat vans needed	Diesel Consumption /year (litres)*	Conversion (0.85kg/liter)	Energy (J)**
2005	60,546,704	3.78E+06	4.54E+09	3.86E+09	1.39E+17
2006	60,618,693	3.79E+06	4.55E+09	3.86E+09	1.39E+17
2007	57,909,309	3.62E+06	4.34E+09	3.69E+09	1.33E+17
2008	58,312,924	3.64E+06	4.37E+09	3.72E+09	1.34E+17
2009	57,696,348	3.61E+06	4.33E+09	3.68E+09	1.33E+17
2010	56,999,009	3.56E+06	4.27E+09	3.63E+09	1.31E+17
2011	56,719,381	3.54E+06	4.25E+09	3.62E+09	1.30E+17
2012	56,468,888	3.53E+06	4.24E+09	3.60E+09	1.30E+17
2013	56,194,853	3.51E+06	4.21E+09	3.58E+09	1.29E+17
2014	56,257,542	3.52E+06	4.22E+09	3.59E+09	1.29E+17
2015	55,430,057	3.46E+06	4.16E+09	3.53E+09	1.28E+17

Appendix B– Distance teaching buildings and computers

B1. Distance Teaching Centers implementation

B.1.1. Concrete and steel

Number of active DTCs as reported by INEP and ABED. Where reported by both, the highest number was considered. Where unknown, a number was considered based on the average number of students/DTC in the years when the number of DTCs was reported.

Year	INEP (units)	ABED (units)	Average Units Considered*
2002			236
2003			289
2004			1794
2005			2919
2006			4507
2007			4852
2008			6896
2009	5904		
2010	5367		
2011	7511		
2012	5432		
2013	5327		
2014	4912		
2015		7463	
2016		5746	
2017	11008		

Adapted from INEP and ABED data.

* Considering 173 students per DTC

Considering 133m^2 per DTC (Oliveira et al., 2018) (g)

Concrete	**1.02E+07**
Steel	**3.20E+05**
Wood	2.40E+04
Plastic	2.30E+03
Iron	3.42E+04
Ceramics	1.89E+05
Glass (windows & lamp bulbs)	2.44E+03
Energy/DTC.yr	**1.07E+07**

B1.2. Computers

Considering 26 units/DTC (Oliveira et al, 2018)

Yr	Computers	Mass (g)*	Lifespan (5yr)(g)
2002	6128	9.19E+07	**1.84E+07**
2003	7513	1.13E+08	**2.25E+07**
2004	46655	7.00E+08	**1.40E+08**
2005	75894	1.14E+09	**2.28E+08**
2006	117175	1.76E+09	**3.52E+08**
2007	126156	1.89E+09	**3.78E+08**
2008	179305	2.69E+09	**5.38E+08**
2009	153504	2.30E+09	**4.61E+08**
2010	139542	2.09E+09	**4.19E+08**
2011	195286	2.93E+09	**5.86E+08**
2012	141232	2.12E+09	**4.24E+08**
2013	138502	2.08E+09	**4.16E+08**
2014	127712	1.92E+09	**3.83E+08**
2015	194038	2.91E+09	**5.82E+08**
2016	149396	2.24E+09	**4.48E+08**
2017	286208	4.29E+09	**8.59E+08**

B2. DTC usage

B2.1. Electricity

Computers (W)*	Datashow (W)**	Lamp bulbs (W)***	Total/yr (W)
1.76E+12	3.39E+10	8.15E+11	**2.61E+12**
2.16E+12	4.16E+10	9.99E+11	**3.20E+12**
1.34E+13	2.58E+11	6.20E+12	**1.99E+13**
2.19E+13	4.20E+11	1.01E+13	**3.24E+13**
3.37E+13	6.49E+11	1.56E+13	**5.00E+13**
3.63E+13	6.99E+11	1.68E+13	**5.38E+13**
5.16E+13	9.93E+11	2.38E+13	**7.65E+13**
4.42E+13	8.50E+11	2.04E+13	**6.55E+13**
4.02E+13	7.73E+11	1.85E+13	**5.95E+13**
5.62E+13	1.08E+12	2.60E+13	**8.33E+13**
4.07E+13	7.82E+11	1.88E+13	**6.02E+13**
3.99E+13	7.67E+11	1.84E+13	**5.91E+13**
3.68E+13	7.07E+11	1.70E+13	**5.45E+13**
5.59E+13	1.07E+12	2.58E+13	**8.27E+13**
4.30E+13	8.27E+11	1.99E+13	**6.37E+13**
8.24E+13	1.59E+12	3.80E+13	**1.22E+14**

* Considering 2 hours/day (Oliveira et al., 2018)(200W/unit)

**Considering 01 unit/DTC (x 250W x 4 hr weekly class x 40 weeks/yr)

***Considering 30 units/DTC x 40W x 4h/day x 200 days/yr

B2.2. Labor (staff)

Considering 120 kcal/h consumption

Year	No. of DTCs	No. of Basic Level staff members*	Workers' metabolic Energy (J)**	No. of Mid-Level staff members*	Workers' metabolic Energy (J)**	No. of Higher Level staff members*	Workers' metabolic Energy (J)**	Total staff energy (J)***
2004	1794	3589	3.61E+12	1794	1.80E+12	1794	1.80E+12	**7.21E+12**
2005	2919	5838	5.87E+12	2919	2.93E+12	2919	2.93E+12	**1.17E+13**
2006	4507	9013	9.06E+12	4507	4.53E+12	4507	4.53E+12	**1.81E+13**
2008	6896	13793	1.39E+13	6896	6.93E+12	6896	6.93E+12	**2.77E+13**
2009	5904	11808	1.19E+13	5904	5.93E+12	5904	5.93E+12	**2.37E+13**
2010	5367	10734	1.08E+13	5367	5.39E+12	5367	5.39E+12	**2.16E+13**
2011	7511	15022	1.51E+13	7511	7.55E+12	7511	7.55E+12	**3.02E+13**
2012	5432	10864	1.09E+13	5432	5.46E+12	5432	5.46E+12	**2.18E+13**
2013	5327	10654	1.07E+13	5327	5.35E+12	5327	5.35E+12	**2.14E+13**
2014	4912	9824	9.87E+12	4912	4.93E+12	4912	4.93E+12	**1.97E+13**
2015	7463	14926	1.50E+13	7463	7.50E+12	7463	7.50E+12	**3.00E+13**
2016	5746	11492	1.15E+13	5746	5.77E+12	5746	5.77E+12	**2.31E+13**
2017	11008	22016	2.21E+13	11008	1.11E+13	11008	1.11E+13	**4.42E+13**

* Considering 2 Basic Level maintenance workers, 1 mid-level secretary, and 1 higher level DTC supervisor

** Considering a daily 8-hour 5 days/week workload

*** Considering 250 days/year

B3. Access to information (Distance Teaching)

B3.1. Computers (students' own units)* and electricity consumption from the use of computers**

***Considering a unit's mass = 16.4 kg x one unit per student.**

**** Considering 2 hours/day, 200 days a year.**

Year	Higher Education	Basic school (ABEAD)	Post Grad (ABED)	Total	Computers - mass (g)*	total/yr (g)	Electricity from students' computer use**	Energy (J)
2002	40,714			40,714	6.68E+08	**1.34E+08**	3.26E+09	**1.17E+13**
2003	49,911			49,911	8.19E+08	**1.64E+08**	3.99E+09	**1.44E+13**
2004	59,611	150,591	61,637	271,839	4.46E+09	**8.92E+08**	2.17E+10	**7.83E+13**
2005	114,642	203,378	104,513	422,533	6.93E+09	**1.39E+09**	3.38E+10	**1.22E+14**
2006	207,206	202,749	143,927	553,882	9.08E+09	**1.82E+09**	4.43E+10	**1.60E+14**
2007	369,766			369,766	6.06E+09	**1.21E+09**	2.96E+10	**1.06E+14**
2008	727,961	283,291	58,000	1,069,252	1.75E+10	**3.51E+09**	8.55E+10	**3.08E+14**
2009	838,125			838,125	1.37E+10	**2.75E+09**	6.71E+10	**2.41E+14**
2010	930,179	53,437	76,663	1,060,279	1.74E+10	**3.48E+09**	8.48E+10	**3.05E+14**
2011	992,927	57,716	135,632	1,186,275	1.95E+10	**3.89E+09**	9.49E+10	**3.42E+14**
2012	1,113,850	25,956	3,989	1,143,795	1.88E+10	**3.75E+09**	9.15E+10	**3.29E+14**
2013	1,153,572	119,890	116,086	1,389,548	2.28E+10	**4.56E+09**	1.11E+11	**4.00E+14**
2014	1,341,842	132,501	92,953	1,567,296	2.57E+10	**5.14E+09**	1.25E+11	**4.51E+14**
2015	1,393,752	114,596	127,465	1,635,813	2.68E+10	**5.37E+09**	1.31E+11	**4.71E+14**
2016	1,494,418	129,137	60,246	1,683,801	2.76E+10	**5.52E+09**	1.35E+11	**4.85E+14**
2017	1,756,982	135,013	182,130	2,074,125	3.40E+10	**6.80E+09**	1.66E+11	**5.97E+14**

Appendix C– Information flows

C.1. Information from teachers to students

C1.1. (Table A) Teachers with a High School level.

Considering energy = 120 kcal/hour x 4186 J/kcal x 800 hours/class group

Percentage of teachers with a High-School degree in every level is indicated in parentheses.

C1.2. (Table B) Teachers with a Graduation level

Considering energy = 120 kcal/hour x 4186 J/kcal x 800 hours/class group

Percentage of teachers with a graduation degree in every level is indicated in parentheses

C1.3. (Table C) Teachers with a Post-Graduation level

Considering energy = 120 kcal/hour x 4186 J/kcal x 800 hours/class group

Percentage of teachers with a Post-Graduation degree in every level is indicated in parentheses

Emergy of Information from teachers to Students = 1% of total emergy.

TABLE A

Kindergarten (85%)		**Primary School (first five grades)(40%)**		**Primary School (last four grades)(60%)**		**Secondary school (40%)**		**Y&A program (40%)**		**Vocational school (40%)**		
Groups (classes)	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Total energy**
300,334	**1.03E+14**	751,193	**1.21E+14**	472,938	**7.60E+13**	234,199	**3.76E+13**					**3.37E+14**
314,274	**1.07E+14**	745,262	**1.20E+14**	477,360	**7.67E+13**	244,476	**3.93E+13**					**3.43E+14**
338,909	**1.16E+14**	751,821	**1.21E+14**	478,241	**7.69E+13**	247,318	**3.98E+13**					**3.53E+14**
327,055	**1.12E+14**	746,328	**1.20E+14**	477,624	**7.68E+13**	246,128	**3.96E+13**	217,546	**3.50E+13**			**3.83E+14**
352,912	**1.21E+14**	757,616	**1.22E+14**	480,908	**7.73E+13**	246,283	**3.96E+13**	187,210	**3.01E+13**	30,081	**4.84E+12**	**3.94E+14**
353,457	**1.21E+14**	707,227	**1.14E+14**	558,206	**8.97E+13**	243,420	**3.91E+13**	166,254	**2.67E+13**	28,497	**4.58E+12**	**3.95E+14**
323,589	**1.11E+14**	712,808	**1.15E+14**	571,565	**9.19E+13**	238,803	**3.84E+13**	134,614	**2.16E+13**	30,692	**4.93E+12**	**3.82E+14**
377,637	**1.29E+14**	715,481	**1.15E+14**	574,240	**9.23E+13**	251,496	**4.04E+13**	157,869	**2.54E+13**	35,637	**5.73E+12**	**4.08E+14**
387,365	**1.32E+14**	705,561	**1.13E+14**	580,800	**9.34E+13**	257,800	**4.14E+13**	151,738	**2.44E+13**	37,302	**6.00E+12**	**4.11E+14**
408,466	**1.40E+14**	716,113	**1.15E+14**	575,162	**9.25E+13**	263,829	**4.24E+13**	151,327	**2.43E+13**	59,403	**9.55E+12**	**4.23E+14**
430,040	**1.47E+14**	713,140	**1.15E+14**	570,541	**9.17E+13**	267,053	**4.29E+13**	149,322	**2.40E+13**	63,797	**1.03E+13**	**4.30E+14**
450,977	**1.54E+14**	712,376	**1.15E+14**	558,570	**8.98E+13**	268,626	**4.32E+13**	150,366	**2.42E+13**	67,981	**1.09E+13**	**4.37E+14**
467,486	**1.60E+14**	707,247	**1.14E+14**	540,462	**8.69E+13**	270,148	**4.34E+13**	145,331	**2.34E+13**	77,938	**1.25E+13**	**4.40E+14**
478,510	**1.63E+14**	697,526	**1.12E+14**	528,306	**8.49E+13**	267,382	**4.30E+13**	136,857	**2.20E+13**	78,525	**1.26E+13**	**4.38E+14**
500,130	**1.71E+14**	695,717	**1.12E+14**	521,169	**8.38E+13**	266,795	**4.29E+13**	138,871	**2.23E+13**	71,628	**1.15E+13**	**4.43E+14**
516,888	**1.77E+14**	691,111	**1.11E+14**	513,584	**8.26E+13**			139,919	**2.25E+13**	68,880	**1.11E+13**	**4.04E+14**

TABLE B

Kindergarten (15%)		Primary School (first five grades)(60%)		Primary School (last four grades)(60%)		Secondary school (60%)		Y&A program (60%)		Vocational school (60%)		
Groups (classes)	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Groups (classes)**	**Energy (J) in 800 hours for each group**	**Total energy**
300,334	**1.81E+13**	751,193	**1.81E+14**	472,938	**1.14E+14**	234,199	**5.65E+13**					**3.70E+14**
314,274	**1.89E+13**	745,262	**1.80E+14**	477,360	**1.15E+14**	244,476	**5.89E+13**					**3.73E+14**
338,909	**2.04E+13**	751,821	**1.81E+14**	478,241	**1.15E+14**	247,318	**5.96E+13**					**3.77E+14**
327,055	**1.97E+13**	746,328	**1.80E+14**	477,624	**1.15E+14**	246,128	**5.93E+13**	217,546	**5.25E+13**			**4.27E+14**
352,912	**2.13E+13**	757,616	**1.83E+14**	480,908	**1.16E+14**	246,283	**5.94E+13**	187,210	**4.51E+13**	30,081	**7.25E+12**	**4.32E+14**
353,457	**2.13E+13**	707,227	**1.71E+14**	558,206	**1.35E+14**	243,420	**5.87E+13**	166,254	**4.01E+13**	28,497	**6.87E+12**	**4.32E+14**
323,589	**1.95E+13**	712,808	**1.72E+14**	571,565	**1.38E+14**	238,803	**5.76E+13**	134,614	**3.25E+13**	30,692	**7.40E+12**	**4.27E+14**
377,637	**2.28E+13**	715,481	**1.73E+14**	574,240	**1.38E+14**	251,496	**6.06E+13**	157,869	**3.81E+13**	35,637	**8.59E+12**	**4.41E+14**
387,365	**2.33E+13**	705,561	**1.70E+14**	580,800	**1.40E+14**	257,800	**6.22E+13**	151,738	**3.66E+13**	37,302	**8.99E+12**	**4.41E+14**
408,466	**2.46E+13**	716,113	**1.73E+14**	575,162	**1.39E+14**	263,829	**6.36E+13**	151,327	**3.65E+13**	59,403	**1.43E+13**	**4.50E+14**
430,040	**2.59E+13**	713,140	**1.72E+14**	570,541	**1.38E+14**	267,053	**6.44E+13**	149,322	**3.60E+13**	63,797	**1.54E+13**	**4.51E+14**
450,977	**2.72E+13**	712,376	**1.72E+14**	558,570	**1.35E+14**	268,626	**6.48E+13**	150,366	**3.63E+13**	67,981	**1.64E+13**	**4.51E+14**
467,486	**2.82E+13**	707,247	**1.71E+14**	540,462	**1.30E+14**	270,148	**6.51E+13**	145,331	**3.50E+13**	77,938	**1.88E+13**	**4.48E+14**
478,510	**2.88E+13**	697,526	**1.68E+14**	528,306	**1.27E+14**	267,382	**6.45E+13**	136,857	**3.30E+13**	78,525	**1.89E+13**	**4.41E+14**
500,130	**3.01E+13**	695,717	**1.68E+14**	521,169	**1.26E+14**	266,795	**6.43E+13**	138,871	**3.35E+13**	71,628	**1.73E+13**	**4.39E+14**
516,888	**3.12E+13**	691,111	**1.67E+14**	513,584	**1.24E+14**			139,919	**3.37E+13**	68,880	**1.66E+13**	**3.72E+14**

TABLE C

Higher Education (graduation)		
Courses	**Class groups**	**Energy (J)***
14,399	57,596	**2.31E+13**
16,453	65,812	**2.64E+13**
18,644	74,576	**3.00E+13**
20,407	81,628	**3.28E+13**
22,101	88,404	**3.55E+13**
23,488	93,952	**3.78E+13**
24,719	98,876	**3.97E+13**
27,827	111,308	**4.47E+13**
28,577	114,308	**4.59E+13**
29,376	117,504	**4.72E+13**
30,718	122,872	**4.94E+13**
30,791	123,164	**4.95E+13**
31,513	126,052	**5.07E+13**
32,028	128,112	**5.15E+13**
32,704	130,816	**5.26E+13**
33,272	133,088	**5.35E+13**

***Considering 4 groups per course**

TABLE D

Distance Teaching Teachers’ information to students.

Considering all teachers hold post –graduation degrees.

Considering 800 hours/year each course.

Data from:	Courses	Professors' energy[1] (J)	x 1%	Tutors[2]	Tutors' energy[3] (J)	x 1%
2002	46	1.85E+10	**1.85E+08**	407	1.64E+11	**1.64E+09**
2003	52	2.09E+10	**2.09E+08**	499	2.01E+11	**2.01E+09**
2004	155	6.23E+10	**6.23E+08**	2718	1.09E+12	**1.09E+10**
2005	366	1.47E+11	**1.47E+09**	4225	1.70E+12	**1.70E+10**
2006	514	2.07E+11	**2.07E+09**	5539	2.23E+12	**2.23E+10**
2007	408	1.64E+11	**1.64E+09**	3698	1.49E+12	**1.49E+10**
2008	779	3.13E+11	**3.13E+09**	10693	4.30E+12	**4.30E+10**
2009	844	3.39E+11	**3.39E+09**	8381	3.37E+12	**3.37E+10**
2010	1076	4.32E+11	**4.32E+09**	10603	4.26E+12	**4.26E+10**
2011	1170	4.70E+11	**4.70E+09**	11863	4.77E+12	**4.77E+10**
2012	1300	5.22E+11	**5.22E+09**	11438	4.60E+12	**4.60E+10**
2013	1490	5.99E+11	**5.99E+09**	13895	5.58E+12	**5.58E+10**
2014	1677	6.74E+11	**6.74E+09**	15673	6.30E+12	**6.30E+10**
2015	1741	7.00E+11	**7.00E+09**	16358	6.57E+12	**6.57E+10**
2016	2194	8.82E+11	**8.82E+09**	16838	6.77E+12	**6.77E+10**
2017	2108	8.47E+11	**8.47E+09**	20741	8.33E+12	**8.33E+10**

Adapted from ABED and INEP data

C2. Information from books

Calculation of books transformity based on Campbell and Cai (2007):

Emergy: 2.79E16 sej (emergy of paper) + 1.83E12 sej (emergy of publishing) + emergy of authorship (assuming 30 days of "post-graduate" labour - 2500 kcal/day * 4186J/kcal *30 days * 2.92E9 sej (assuming 0.5% of population) = 9.44E17 sej
Transformity: 9.44E17 seJ/3.66E10 Joules = **2.58E7 sej/j**

Information from books is 10% of the total books energy.

For books totals, refer to Appendix A2.2.

C3. Students’ previously acquired Information

Considering 10% of students’ previously acquired knowledge is used during classes.

Students’ knowledge level I = previously uneducated;

students’ knowledge level II = students who completed basic school;

students’ knowledge level III = students with a graduation degree.

Year	**Std Level I (in-class)***	**Std Level I (DT)***	**Total energy (10%) Level I (J)**	**Std Level II (in-class)****	**Std Level II (DT)****	**Total energy (10%) Level II (J)**	**Level III (in-class)*****	**Level III (DT)*****	**Total energy (10%) Level III (J)**
2002	2.71E+14	0.00E+00	**2.71E+14**	1.94E+15	1.64E+12	**1.94E+15**	1.40E+14	0.00E+00	**1.40E+14**
2003	2.81E+14	0.00E+00	**2.81E+14**	1.95E+15	2.01E+12	**1.95E+15**	1.56E+14	0.00E+00	**1.56E+14**
2004	2.77E+14	6.05E+12	**2.83E+14**	1.95E+15	2.40E+12	**1.95E+15**	1.67E+14	2.48E+12	**1.70E+14**
2005	2.90E+14	8.17E+12	**2.98E+14**	2.00E+15	4.61E+12	**2.01E+15**	1.79E+14	4.20E+12	**1.83E+14**
2006	2.82E+14	8.15E+12	**2.90E+14**	1.92E+15	8.33E+12	**1.93E+15**	1.88E+14	5.78E+12	**1.94E+14**
2007	2.58E+14	0.00E+00	**2.58E+14**	1.81E+15	1.49E+13	**1.82E+15**	1.96E+14	0.00E+00	**1.96E+14**
2008	2.66E+14	1.14E+13	**2.77E+14**	1.81E+15	2.93E+13	**1.84E+15**	2.04E+14	2.33E+12	**2.06E+14**
2009	2.72E+14	0.00E+00	**2.72E+14**	1.80E+15	3.37E+13	**1.83E+15**	2.06E+14	0.00E+00	**2.06E+14**
2010	2.72E+14	2.15E+12	**2.74E+14**	1.76E+15	3.74E+13	**1.80E+15**	2.19E+14	3.08E+12	**2.22E+14**
2011	2.81E+14	2.32E+12	**2.84E+14**	1.73E+15	3.99E+13	**1.77E+15**	2.31E+14	5.45E+12	**2.36E+14**
2012	2.94E+14	1.04E+12	**2.95E+14**	1.70E+15	4.48E+13	**1.75E+15**	2.38E+14	1.60E+11	**2.38E+14**
2013	3.06E+14	4.82E+12	**3.11E+14**	1.67E+15	4.64E+13	**1.71E+15**	2.47E+14	4.66E+12	**2.52E+14**
2014	3.16E+14	5.32E+12	**3.22E+14**	1.64E+15	5.39E+13	**1.69E+15**	2.61E+14	3.74E+12	**2.64E+14**
2015	3.20E+14	4.61E+12	**3.25E+14**	1.60E+15	5.60E+13	**1.65E+15**	2.67E+14	5.12E+12	**2.72E+14**
2016	3.32E+14	5.19E+12	**3.38E+14**	1.59E+15	6.01E+13	**1.65E+15**	2.63E+14	2.42E+12	**2.66E+14**
2017	3.42E+14	5.43E+12	**3.47E+14**	1.57E+15	7.06E+13	**1.64E+15**	2.62E+14	7.32E+12	**2.70E+14**

Appendix D. Different approaches to calculating the information flows in systems by different authors.

Author(s)	Unit studied	UEV for teachers' and students' work calculation method	Approach to calculating the flows of information in the system	Resulting contribution from information to the systems
Qin et al. (2000)	Mai Po marshes education function (Hong Kong)	The emergy of Hong Kong (1998) divided by all individuals in a given level of knowledge	The "knowledge contribution" is, in fact, the sum of the transformity (UEV) of the education staff members, for 1 year.	80%
Meillaud et al. (2005)	LESO buiding in the Swiss Federal Institute of Technology (EPFL) in Lausanne, Switzerland.	The emergy of the U.S.A. (1980) divided by all individuals in a given level of knowledge (taken from Odum, 1996)	Number of individuals (students, faculty, secretaries & tech. staff) present in the premises *(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(0.7)*(365 days/yr), considering 30% of the activities are performed outside the school building.	94.6%
Almeida et al. (2013)	The Engineering school at Paulista University, Brazil	a- UEV of professors' work: the emergy of Brazil (2002) divided by the number of college professors in Brazil in 2007; b- UEV of students' work: the emergy of Brazil divided by the number of high school graduates in 2007	Emergy of Teaching and Learning (1% of teacher-to-student info + 1% of books-to-student info + 10% of students' previously acquired knowledge), 5 hours/day, 205 days/year, then multiplied by the information carriers' respective UEVs	85%
Oliveira et al. (2018)	In-class Technical course on Management at IFSULDEMINAS, Brazil	Emergy of Brazil (2010) divided by all individuals in a given level of knowledge	Emergy of Teaching and Learning (1% of teacher-to-student info + 10% of books-to-student info + 10% of students' previously acquired knowledge), 5 hours/day, 205 days/year, then multiplied by the information carriers' respective UEVs	32%
This work	The Brazilian education system	Emergy of Brazil (annually updated from 2002 to 2017) divided by all individuals in a given level of knowledge	Emergy of Teaching and Learning (1% of teacher-to-student info + 10% of books-to-student info + 10% of students' previously acquired knowledge), 5 hours/day, 205 days/year, then multiplied by the information carriers' respective UEVs	48% (2002) to 64% (2017)

Appendix E. The emergy of the Brazilian education system

E1. Emergy calculation of the Brazilian education system from 2002 to 2017.

The emergy values comply with the 15.83 x 10^{24} baseline.

2002

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contribution
	Campus implementation					
1	Concrete	g	1.38E+13	2.59E+09	3.57E+22	19.7%
2	Steel	g	4.25E+11	6.93E+09	2.95E+21	1.6%
3	Computer	g	2.65E+10	8.90E+10	2.36E+21	1.3%
	Subtotal				**4.10E+22**	22.6%
	Campus usage					
4	Electricity	J	1.64E+16	2.77E+05	4.54E+21	2.5%
5	Workbooks	J	7.25E+13	2.58E+07	1.87E+21	1.0%
6	Labor	J	2.76E+15	1.07E+07	2.95E+22	16%
	Subtotal				**3.59E+22**	19.8%
	Access to information					
7	Transportation	g	1.22E+12	4.15E+09	5.06E+21	3%
8	Fuel (diesel)	J	1.34E+17	1.13E+05	1.51E+22	8%
9	Computer (students' units)	g	1.34E+08	8.90E+10	1.19E+19	<1
10	Electricity	J	1.17E+13	2.77E+05	3.24E+18	<1
	Subtotal				**2.02E+22**	11%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	3.37E+12	3.55E+07	1.20E+20	<1
12	Information Teacher (2) --> Student (1%)	J	3.70E+12	6.28E+07	2.32E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	2.33E+11	2.18E+08	5.08E+19	<1
14	Information books --> students (10%)	J	7.25E+12	2.58E+07	1.87E+20	<1
15	Information brought in by students (1) (10%)	J	2.71E+14	2.11E+07	5.72E+21	3.2%
16	Information brought in by students (2) (10%)	J	1.94E+15	3.55E+07	6.89E+22	38.0%
17	Information brought in by students (3) (10%)	J	1.40E+14	6.28E+07	8.79E+21	4.9%
	Subtotal				**8.40E+22**	49.6%
	Total Emergy				**1.81E+23**	100%

2003

Note	Description	Unit/yr	Energy flows	UEV (seJ/unit)	Emergy	Contribution
	Campus implementation					
1	Concrete	g	1.36E+13	2.59E+09	3.52E+22	18.8%
2	Steel	g	4.21E+11	6.93E+09	2.92E+21	1.6%
3	Computer	g	2.62E+10	8.90E+10	2.33E+21	1.2%
	Subtotal				**4.04E+22**	21.6%
	Campus usage					
4	Electricity	J	1.63E+16	2.77E+05	4.52E+21	2.4%
5	Workbooks	J	7.32E+13	2.58E+07	1.89E+21	1.0%
6	Labor	J	2.74E+15	1.12E+07	3.07E+22	16.4%
	Subtotal				**3.71E+22**	19.8%
	Access to information					
7	Transportation	g	1.24E+12	4.15E+09	5.15E+21	2.7%
8	Fuel (diesel)	J	1.37E+17	1.13E+05	1.55E+22	8.3%
9	Computer (students' units)	g	1.64E+08	8.90E+10	1.46E+19	<1
10	Electricity	J	1.44E+13	2.77E+05	3.99E+18	<1
	Subtotal				**2.06E+22**	15.8%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	3.43E+12	3.73E+07	1.28E+20	<1
12	Information Teacher (2) --> Student (1%)	J	3.73E+12	6.24E+07	2.33E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	2.66E+11	2.11E+08	5.62E+19	<1
14	Information books --> students (10%)	J	7.32E+12	2.58E+07	1.89E+20	<1
15	Information brought in by students (1) (10%)	J	2.81E+14	2.22E+07	6.24E+21	3.3%
16	Information brought in by students (2) (10%)	J	1.95E+15	3.73E+07	7.28E+22	38.8%
17	Information brought in by students (3) (10%)	J	1.56E+14	6.24E+07	9.73E+21	5.19%
	Subtotal				**8.94E+22**	47.7%
	Total Emergy				**1.88E+23**	100%

2004

Note	Description	Unit/yr	Energy flows	UEV (seJ/unit)	Emergy	Contribution
	Campus implementation					
1	Concrete	g	1.35E+13	2.59E+09	3.50E+22	18.1%
2	Steel	g	4.17E+11	6.93E+09	2.89E+21	1.5%
3	Computer	g	2.61E+10	8.90E+10	2.33E+21	1.2%
	Subtotal				**4.02E+22**	20.8%
	Campus usage					
4	Electricity	J	1.61E+16	2.77E+05	4.47E+21	2.3%
5	Workbooks	J	7.36E+13	2.58E+07	1.90E+21	1.0%
6	Labor	J	2.71E+15	1.17E+07	3.17E+22	16.4%
	Subtotal				**3.80E+22**	19.7%
	Access to information					
7	Transportation	g	1.24E+12	4.15E+09	5.15E+21	2.7%
8	Fuel (diesel)	J	1.37E+17	1.13E+05	1.55E+22	8.0%
9	Computer (students' units)	g	8.92E+08	8.90E+10	7.94E+19	<1
10	Electricity	J	7.83E+13	2.77E+05	2.17E+19	<1
	Subtotal				**2.07E+22**	14.7%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	3.57E+12	3.90E+07	1.39E+20	<1
12	Information Teacher (2) --> Student (1%)	J	3.73E+12	6.21E+07	2.32E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	3.12E+11	2.05E+08	6.39E+19	<1
14	Information books --> students (10%)	J	7.36E+12	2.58E+07	1.90E+20	<1
15	Information brought in by students (1) (10%)	J	2.83E+14	2.32E+07	6.57E+21	3.4%
16	Information brought in by students (2) (10%)	J	1.95E+15	3.90E+07	7.61E+22	39.5%
17	Information brought in by students (3) (10%)	J	1.69E+14	6.21E+07	1.05E+22	5.5%
	Subtotal				**9.39E+22**	48.7%
	Total Emergy				**1.93E+23**	100%

2005

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.33E+13	2.59E+09	3.44E+22	18.0%
2	Steel	g	4.11E+11	6.93E+09	2.85E+21	1.5%
3	Computer	g	2.59E+10	8.90E+10	2.31E+21	1.2%
	Subtotal				**3.96E+22**	20.7%
	Campus usage					
4	Electricity	J	1.59E+16	2.77E+05	4.41E+21	2.3%
5	Workbooks	J	7.47E+13	2.58E+07	1.93E+21	1.0%
6	Labor	J	2.67E+15	1.14E+07	3.05E+22	15.9%
	Subtotal				**3.68E+22**	19.2%
	Access to information					
7	Transportation	g	1.26E+12	4.15E+09	5.23E+21	2.7%
8	Fuel (diesel)	J	1.39E+17	1.13E+05	1.57E+22	8.2%
9	Computer (students' units)	g	1.39E+09	8.90E+10	1.24E+20	<1
10	Electricity	J	1.22E+14	2.77E+05	3.38E+19	<1
	Subtotal				**2.11E+22**	13.6%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	3.83E+12	3.80E+07	1.46E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.27E+12	4.75E+07	2.03E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	3.46E+11	1.86E+08	6.44E+19	<1
14	Information books --> students (10%)	J	7.47E+12	2.58E+07	1.93E+20	<1
15	Information brought in by students (1) (10%)	J	2.98E+14	2.81E+07	8.38E+21	4.4%
16	Information brought in by students (2) (10%)	J	2.00E+15	3.80E+07	7.62E+22	39.8%
17	Information brought in by students (3) (10%)	J	1.83E+14	4.75E+07	8.70E+21	4.5%
	Subtotal				**9.39E+22**	49%
	Total Emergy				**1.91E+23**	100%

2006

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.31E+13	2.59E+09	3.40E+22	17.5%
2	Steel	g	4.06E+11	6.93E+09	2.81E+21	1.5%
3	Computer	g	2.56E+10	8.90E+10	2.28E+21	1.2%
	Subtotal				**3.90E+22**	20.2%
	Campus usage					
4	Electricity	J	1.57E+16	2.77E+05	4.35E+21	2.2%
5	Workbooks	J	7.46E+13	2.58E+07	1.92E+21	1.0%
6	Labor	J	2.64E+15	1.11E+07	2.93E+22	15.1%
	Subtotal				**3.56E+22**	18.4%
	Access to information					
7	Transportation	g	1.26E+12	4.15E+09	5.23E+21	2.7%
8	Fuel (diesel)	J	1.39E+17	1.13E+05	1.57E+22	8.1%
9	Computer (students' units)	g	1.82E+09	8.90E+10	1.62E+20	<1
10	Electricity	J	1.60E+14	2.77E+05	4.43E+19	<1
	Subtotal				**2.11E+22**	10.8%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	3.94E+12	4.12E+07	1.62E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.32E+12	4.64E+07	2.00E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	3.80E+11	2.23E+09	8.47E+20	<1
14	Information books --> students (10%)	J	7.46E+12	2.58E+07	1.92E+20	<1
15	Information brought in by students (1) (10%)	J	2.92E+14	2.74E+07	8.00E+21	4.1%
16	Information brought in by students (2) (10%)	J	1.93E+15	4.12E+07	7.94E+22	41.0%
17	Information brought in by students (3) (10%)	J	1.94E+14	4.64E+07	8.99E+21	4.6%
	Subtotal				**9.78E+22**	50.6%
	Total Emergy				**1.94E+23**	100.0%

2007

Note	Description	Unit/ yr	2007	UEV (seJ/unit)		Contri bution
	Campus implementation					
1	Concrete	g	1.27E+13	2.59E+09	3.29E+22	18.2%
2	Steel	g	3.95E+11	6.93E+09	2.74E+21	1.5%
3	Computer	g	2.49E+10	8.90E+10	2.22E+21	1.2%
	Subtotal				**3.79E+22**	20.9%
	Campus usage					
4	Electricity	J	1.52E+16	2.77E+05	4.22E+21	2.3%
5	Workbooks	J	7.02E+13	2.58E+07	1.81E+21	<1
6	Labor	J	2.57E+15	1.07E+07	2.75E+22	15.2%
	Subtotal				**3.35E+22**	18.4%
	Access to information					
7	Transportation	g	1.21E+12	4.15E+09	5.02E+21	2.8%
8	Fuel (diesel)	J	1.33E+17	1.13E+05	1.50E+22	8.3%
9	Computer (students' units)	g	1.21E+09	8.90E+10	1.08E+20	<1
10	Electricity	J	1.06E+14	2.77E+05	2.94E+19	<1
	Subtotal				**2.02E+22**	11.2%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	3.95E+12	3.97E+07	1.57E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.32E+12	4.47E+07	1.93E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	3.94E+11	2.15E+09	8.47E+20	<1
14	Information books --> students (10%)	J	7.02E+12	2.58E+07	1.81E+20	<1
15	Information brought in by students (1) (10%)	J	2.58E+14	2.64E+07	6.81E+21	3.8%
16	Information brought in by students (2) (10%)	J	1.83E+15	3.97E+07	7.26E+22	40.1%
17	Information brought in by students (3) (10%)	J	1.96E+14	4.47E+07	8.76E+21	4.8%
	Subtotal				**8.96E+22**	49.5%
	Total Emergy				**1.81E+23**	100.0%

2008

Note	Description	Unit/ yr	2008	UEV (seJ/unit)		Contri bution
	Campus implementation					
1	Concrete	g	1.28E+13	2.59E+09	3.32E+22	15.7%
2	Steel	g	3.98E+11	6.93E+09	2.76E+21	1.3%
3	Computer	g	2.53E+10	8.90E+10	2.25E+21	1.1%
	Subtotal				**3.82E+22**	18.1%
	Campus usage					
4	Electricity	J	1.54E+16	2.77E+05	4.26E+21	2.0%
5	Workbooks	J	7.13E+13	2.58E+07	1.84E+21	<1
6	Labor	J	2.60E+15	1.32E+07	3.43E+22	16.2%
	Subtotal				**4.04E+22**	19.0%
	Access to information					
7	Transportation	g	1.21E+12	4.15E+09	5.02E+21	2.4%
8	Fuel (diesel)	J	1.34E+17	1.13E+05	1.51E+22	7.2%
9	Computer (students' units)	g	3.51E+09	8.90E+10	3.12E+20	<1
10	Electricity	J	3.08E+14	2.77E+05	8.53E+19	<1
	Subtotal				**2.06E+22**	10.2%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	3.82E+12	4.89E+07	1.87E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.27E+12	5.50E+07	2.35E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	4.43E+11	2.64E+09	1.17E+21	<1
14	Information books --> students (10%)	J	7.15E+12	2.58E+07	1.84E+20	<1
15	Information brought in by students (1) (10%)	J	2.77E+14	3.25E+07	9.02E+21	4.3%
16	Information brought in by students (2) (10%)	J	1.84E+15	4.89E+07	8.99E+22	42.6%
17	Information brought in by students (3) (10%)	J	2.06E+14	5.50E+07	1.13E+22	5.4%
	Subtotal				**1.12E+23**	53.1%
	Total Emergy				**2.11E+23**	100.0%

2009

Note	Description	Unit/yr	Energy flows	UEV (seJ/unit)	Emergy	Contribution
	Campus implementation					
1	Concrete	g	1.28E+13	2.59E+09	3.30E+22	14.8%
2	Steel	g	3.94E+11	6.93E+09	2.73E+21	1.2%
3	Computer	g	2.49E+10	8.90E+10	2.22E+21	1.0%
	Subtotal				**3.80E+22**	17.0%
	Campus usage					
4	Electricity	J	1.52E+16	2.77E+05	4.21E+21	1.9%
5	Workbooks	J	7.10E+13	2.58E+07	1.83E+21	<1
6	Labor	J	2.56E+15	1.44E+07	3.69E+22	16.6%
	Subtotal				**4.30E+22**	19.2%
	Access to information					
7	Transportation	g	1.20E+12	4.15E+09	4.98E+21	2.2%
8	Fuel (diesel)	J	1.33E+17	1.13E+05	1.50E+22	6.7%
9	Computer (students' units)		2.75E+09	8.90E+10	2.45E+20	<1
10	Electricity		2.41E+14	2.77E+05	6.68E+19	<1
	Subtotal				**2.03E+22**	9.2%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.08E+12	5.32E+07	2.17E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.41E+12	5.98E+07	2.64E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	4.84E+11	2.87E+09	1.39E+21	<1
14	Information books --> students (10%)	J	7.10E+12	2.58E+07	1.83E+20	<1
15	Information brought in by students (1) (10%)	J	2.72E+14	3.54E+07	9.63E+21	4.3%
16	Information brought in by students (2) (10%)	J	1.83E+15	5.32E+07	9.76E+22	43.8%
17	Information brought in by students (3) (10%)	J	2.06E+14	5.98E+07	1.23E+22	5.5%
	Subtotal				**1.22E+23**	54.6%
	Total Emergy				**2.23E+23**	100.0%

2010

Note	Description	Unit/yr	Energy flows	UEV (seJ/unit)	Emergy	Contribution
	Campus implementation					
1	Concrete	g	1.25E+13	2.59E+09	3.24E+22	12.9%
2	Steel	g	3.76E+11	6.93E+09	2.60E+21	1.0%
3	Computer	g	2.46E+10	8.90E+10	2.19E+21	<1
	Subtotal				**3.72E+22**	14.9%
	Campus usage					
4	Electricity	J	1.50E+16	2.77E+05	4.16E+21	1.7%
5	Workbooks	J	7.01E+13	2.58E+07	1.81E+21	<1
6	Labor	J	2.53E+15	1.71E+07	4.33E+22	17.3%
	Subtotal				**4.93E+22**	19.6%
	Access to information					
7	Transportation	g	1.19E+12	4.15E+09	4.94E+21	2.0%
8	Fuel (diesel)	J	1.31E+17	1.13E+05	1.48E+22	5.9%
9	Computer (students' units)	g	3.48E+09	8.90E+10	3.10E+20	<1
10	Electricity	J	3.05E+14	2.77E+05	8.45E+19	<1
	Subtotal				**2.01E+22**	8.0%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.11E+12	6.35E+07	2.61E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.41E+12	7.14E+07	3.15E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	5.06E+11	3.43E+09	1.73E+21	<1
14	Information books --> students (10%)	J	7.01E+12	2.58E+07	1.81E+20	<1
15	Information brought in by students (1) (10%)	J	2.74E+14	4.22E+07	1.16E+22	4.6%
16	Information brought in by students (2) (10%)	J	1.80E+15	6.35E+07	1.14E+23	45.5%
17	Information brought in by students (3) (10%)	J	2.22E+14	7.14E+07	1.59E+22	6.3%
	Subtotal				**1.44E+23**	57.5%
	Total Emergy				**2.51E+23**	100.0%

2011

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.24E+13	2.59E+09	3.22E+22	12.2%
2	Steel	g	3.84E+11	6.93E+09	2.66E+21	1.0%
3	Computer	g	2.45E+10	8.90E+10	2.18E+21	<1
	Subtotal				**3.70E+22**	14.1%
	Campus usage					
4	Electricity	J	1.49E+16	2.77E+05	4.12E+21	1.6%
5	Workbooks	J	7.03E+13	2.58E+07	1.81E+21	<1
6	Labor	J	2.51E+15	1.84E+07	4.62E+22	17.5%
	Subtotal				**5.21E+22**	19.7%
	Access to information					
7	Transportation	g	1.18E+12	4.15E+09	4.90E+21	1.9%
8	Fuel (diesel)	J	1.30E+17	1.13E+05	1.47E+22	5.6%
9	Computer (students' units)	g	3.89E+09	8.90E+10	3.46E+20	<1
10	Electricity	J	3.42E+14	2.77E+05	9.47E+19	<1
	Subtotal				**2.00E+22**	7.6%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.23E+12	6.82E+07	2.89E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.50E+12	7.67E+07	3.45E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	5.25E+11	3.68E+09	1.93E+21	<1
14	Information books --> students (10%)	J	6.86E+12	2.58E+07	1.77E+20	<1
15	Information brought in by students (1) (10%)	J	2.83E+14	4.54E+07	1.29E+22	4.9%
16	Information brought in by students (2) (10%)	J	1.77E+15	6.82E+07	1.21E+23	45.8%
17	Information brought in by students (3) (10%)	J	2.36E+14	7.67E+07	1.81E+22	6.9%
	Subtotal				**1.54E+23**	58.6%
	Total Emergy				**2.64E+23**	100.0%

2012

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.24E+13	2.59E+09	3.22E+22	11.4%
2	Steel	g	3.84E+11	6.93E+09	2.66E+21	<1
3	Computer	g	2.43E+10	8.90E+10	2.16E+21	<1
	Subtotal				**3.70E+22**	13.1%
	Campus usage					
4	Electricity	J	1.48E+16	2.77E+05	4.11E+21	1.5%
5	Workbooks	J	6.95E+13	2.58E+07	1.79E+21	<1
6	Labor	J	2.50E+15	2.02E+07	5.05E+22	17.9%
	Subtotal				**5.64E+22**	20.0%
	Access to information					
7	Transportation	g	1.18E+12	4.15E+09	4.90E+21	1.7%
8	Fuel (diesel)	J	1.30E+17	1.13E+05	1.47E+22	5.2%
9	Computer (students' units)	g	3.75E+09	8.90E+10	3.34E+20	<1
10	Electricity	J	3.29E+14	2.77E+05	9.11E+19	<1
	Subtotal				**2.00E+22**	7.1%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.30E+12	7.48E+07	3.22E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.51E+12	8.41E+07	3.79E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	5.45E+11	4.04E+09	2.20E+21	<1
14	Information books --> students (10%)	J	6.95E+12	2.58E+07	1.79E+20	<1
15	Information brought in by students (1) (10%)	J	2.95E+14	4.97E+07	1.47E+22	5.2%
16	Information brought in by students (2) (10%)	J	1.74E+15	7.48E+07	1.31E+23	46.3%
17	Information brought in by students (3) (10%)	J	2.40E+14	8.41E+07	2.02E+22	7.1%
	Subtotal				**1.68E+23**	59.8%
	Total Emergy				**2.82E+23**	100.0%

2013

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.22E+13	2.59E+09	3.16E+22	10.6%
2	Steel	g	3.80E+11	6.93E+09	2.63E+21	<1
3	Computer	g	2.40E+10	8.90E+10	2.14E+21	<1
	Subtotal				**3.64E+22**	12.2%
	Campus usage					
4	Electricity	J	1.47E+16	2.77E+05	4.07E+21	1.4%
5	Workbooks	J	6.88E+13	2.58E+07	1.78E+21	<1
6	Labor	J	2.47E+15	2.20E+07	5.44E+22	18.1%
	Subtotal				**6.02E+22**	20,0%
	Access to information					
7	Transportation	g	1.17E+12	4.15E+09	4.86E+21	1.6%
8	Fuel (diesel)	J	1.29E+17	1.13E+05	1.46E+22	4.9%
9	Computer (students' units)	g	4.56E+09	8.90E+10	4.06E+20	<1
10	Electricity	J	4.00E+14	2.77E+05	1.11E+20	<1
	Subtotal				**1.99E+22**	6.7%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.37E+12	8.14E+07	3.55E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.51E+12	9.16E+07	4.13E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	5.56E+11	4.40E+09	2.45E+21	<1
14	Information books --> students (10%)	J	6.88E+12	2.58E+07	1.78E+20	<1
15	Information brought in by students (1) (10%)	J	3.11E+14	5.42E+07	1.68E+22	5.6%
16	Information brought in by students (2) (10%)	J	1.72E+15	8.14E+07	1.40E+23	46.6%
17	Information brought in by students (3) (10%)	J	2.52E+14	9.16E+07	2.31E+22	7.7%
	Subtotal				**1.83E+23**	61.1%
	Total Emergy				**3.00E+23**	100.0%

2014

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.21E+13	2.59E+09	3.14E+22	9.8%
2	Steel	g	3.76E+11	6.93E+09	2.60E+21	<1
3	Computer	g	2.37E+10	8.90E+10	2.11E+21	<1
	Subtotal				**3.61E+22**	11.3%
	Campus usage					
4	Electricity	J	1.45E+16	2.77E+05	4.02E+21	1.3%
5	Workbooks	J	6.86E+13	2.58E+07	1.77E+21	<1
6	Labor	J	2.45E+15	2.38E+07	5.83E+22	18.3%
	Subtotal				**6.41E+22**	20.1%
	Access to information					
7	Transportation	g	1.17E+12	4.15E+09	4.86E+21	1.5%
8	Fuel (diesel)	J	1.29E+17	1.13E+05	1.46E+22	4.6%
9	Computer (students' units)	g	5.14E+09	8.90E+10	4.57E+20	<1
10	Electricity	J	4.51E+14	2.77E+05	1.25E+20	<1
	Subtotal				**2.00E+22**	6.3%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.40E+12	8.83E+07	3.88E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.48E+12	9.94E+07	4.45E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	5.76E+11	4.77E+09	2.75E+21	<1
14	Information books --> students (10%)	J	6.86E+12	2.58E+07	1.77E+20	<1
15	Information brought in by students (1) (10%)	J	3.21E+14	5.87E+07	1.89E+22	5.9%
16	Information brought in by students (2) (10%)	J	1.69E+15	8.83E+07	1.50E+23	46.9%
17	Information brought in by students (3) (10%)	J	2.65E+14	9.94E+07	2.63E+22	8.3%
	Subtotal				**1.99E+23**	62.3%
	Total Emergy				**3.19E+23**	100.0%

2015

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.20E+13	2.59E+09	3.11E+22	9.4%
2	Steel	g	3.71E+11	6.93E+09	2.57E+21	<1
3	Computer	g	2.35E+10	8.90E+10	2.09E+21	<1
	Subtotal				**3.58E+22**	10.8%
	Campus usage					
4	Electricity	J	1.44E+16	2.77E+05	3.98E+21	1.2%
5	Workbooks	J	6.73E+13	2.58E+07	1.74E+21	<1
6	Labor	J	2.43E+15	2.54E+07	6.17E+22	18.6%
	Subtotal				**6.74E+22**	20.3%
	Access to information					
7	Transportation	g	1.15E+12	4.15E+09	4.77E+21	1.4%
8	Fuel (diesel)	J	1.28E+17	1.13E+05	1.45E+22	4.4%
9	Computer (students' units)	g	5.37E+09	8.90E+10	4.78E+20	<1
10	Electricity	J	4.71E+14	2.77E+05	1.30E+20	<1
	Subtotal				**1.98E+22**	6.0%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.38E+12	9.41E+07	4.12E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.41E+12	1.06E+08	4.67E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	5.88E+11	5.08E+09	2.98E+21	<1
14	Information books --> students (10%)	J	6.73E+12	2.58E+07	1.74E+20	<1
15	Information brought in by students (1) (10%)	J	3.25E+14	6.26E+07	2.03E+22	6.1%
16	Information brought in by students (2) (10%)	J	1.66E+15	9.41E+07	1.56E+23	46.9%
17	Information brought in by students (3) (10%)	J	2.72E+14	1.06E+08	2.88E+22	8.7%
	Subtotal				**2.09E+23**	63.0%
	Total Emergy				**3.32E+23**	100.0%

2016

Note	Description	Unit/ yr	Energy flows	UEV (seJ/unit)	Emergy	Contri bution
	Campus implementation					
1	Concrete	g	1.20E+13	2.59E+09	3.09E+22	8.7%
2	Steel	g	3.71E+11	6.93E+09	2.57E+21	<1
3	Computer	g	2.34E+10	8.90E+10	2.08E+21	<1
	Subtotal				**3.56E+22**	10.1%
	Campus usage					
4	Electricity	J	1.44E+16	2.77E+05	3.98E+21	1.1%
5	Workbooks	J	6.68E+13	2.58E+07	1.72E+21	<1
6	Labor	J	2.41E+15	2.76E+07	6.66E+22	18.8%
	Subtotal				**7.23E+22**	20.4%
	Access to information					
7	Transportation	g	1.17E+12	4.15E+09	4.86E+21	1.4%
8	Fuel (diesel)	J	1.29E+17	1.13E+05	1.46E+22	4.1%
9	Computer (students' units)		5.52E+09	8.90E+10	4.91E+20	<1
10	Electricity		4.84E+14	2.77E+05	1.34E+20	<1
	Subtotal				**2.01E+22**	5.7%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.43E+12	1.02E+08	4.52E+20	<1
12	Information Teacher (2) --> Student (1%)	J	4.39E+12	1.15E+08	5.05E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	6.03E+11	5.08E+09	3.06E+21	<1
14	Information books --> students (10%)	J	6.68E+12	2.58E+07	1.72E+20	<1
15	Information brought in by students (1) (10%)	J	3.37E+14	6.79E+07	2.29E+22	6.5%
16	Information brought in by students (2) (10%)	J	1.65E+15	1.02E+08	1.68E+23	47.6%
17	Information brought in by students (3) (10%)	J	2.65E+14	1.15E+08	3.05E+22	8.6%
	Subtotal				**2.26E+23**	63.9%
	Total Emergy				**3.54E+23**	100.0%

2017

Note	Description	**Unit/ yr**	**Energy flows**	**UEV (seJ/unit)**	**Emergy**	**Contri bution**
	Campus implementation					
1	Concrete	g	1.19E+13	2.59E+09	3.08E+22	8.2%
2	Steel	g	3.70E+11	6.93E+09	2.56E+21	<1
3	Computer	g	2.37E+10	8.90E+10	2.11E+21	<1
	Subtotal				**3.55E+22**	9.5%
	Campus usage					
4	Electricity	J	1.42E+16	2.77E+05	3.94E+21	1.1%
5	Workbooks	J	6.68E+13	2.58E+07	1.72E+21	<1
6	Labor	J	2.41E+15	2.95E+07	7.12E+22	19.0%
	Subtotal				**7.69E+22**	20.5%
	Access to information					
7	Transportation	g	1.16E+12	4.15E+09	4.81E+21	1.3%
8	Fuel (diesel)	J	1.28E+17	1.13E+05	1.45E+22	3.9%
9	Computer (students' units)	g	6.80E+09	8.90E+10	6.05E+20	<1
10	Electricity	J	5.97E+14	2.77E+05	1.65E+20	<1
	Subtotal				**2.00E+22**	5.4%
	Information flows					
11	Information Teacher (1) --> Student (1%)	J	4.04E+12	1.09E+08	4.40E+20	<1
12	Information Teacher (2) --> Student (1%)	J	3.72E+12	1.23E+08	4.58E+20	<1
13	Information Teachers & Tutors (3) --> Student (1%)	J	6.27E+11	5.89E+09	3.69E+21	1.0%
14	Information books --> students (10%)	J	6.68E+12	2.58E+07	1.72E+20	<1
15	Information brought in by students (1) (10%)	J	3.47E+14	7.25E+07	2.52E+22	6.7%
16	Information brought in by students (2) (10%)	J	1.64E+15	1.09E+08	1.79E+23	47.8%
17	Information brought in by students (3) (10%)	J	2.69E+14	1.23E+08	3.31E+22	8.8%
	Subtotal				**2.42E+23**	64.7%
	Total Emergy				**3.74E+23**	100.0%

E2. Emergy accounting of a hypothetical full migration to the Distance Teaching mode.

DISTANCE TEACHING

Year	Implementation	Usage	Access to Info	Info flows	**Total Emergy**
2002	7.19E+21	1.13E+23	2.18E+22	8.44E+22	**2.27E+23**
2003	7.29E+21	1.59E+23	2.21E+22	9.01E+22	**2.78E+23**
2004	3.80E+22	9.87E+22	1.01E+23	2.37E+23	**4.75E+23**
2005	3.27E+22	8.27E+22	8.33E+22	3.22E+23	**5.21E+23**
2006	2.78E+22	6.81E+22	6.02E+22	2.60E+23	**4.16E+23**
2007	1.59E+22	3.99E+22	2.12E+22	1.25E+23	**2.02E+23**
2008	1.17E+22	3.36E+22	3.17E+22	1.64E+23	**2.41E+23**
2009	1.45E+22	2.68E+22	2.17E+22	1.32E+23	**1.95E+23**
2010	7.05E+21	2.61E+22	2.45E+22	1.77E+23	**2.34E+23**
2011	9.33E+21	3.62E+22	2.58E+22	2.02E+23	**2.73E+23**
2012	6.00E+21	2.58E+22	2.22E+22	1.96E+23	**2.50E+23**
2013	5.66E+21	2.67E+22	2.59E+22	2.38E+23	**2.96E+23**
2014	4.51E+21	2.32E+22	2.52E+22	2.51E+23	**3.04E+23**
2015	5.78E+21	3.45E+22	2.51E+22	2.67E+23	**3.32E+23**
2016	7.66E+21	2.73E+22	2.41E+22	2.76E+23	**3.36E+23**
2017	1.28E+22	4.60E+22	2.52E+22	3.12E+23	**3.96E+23**

Total students	Preschool	%	**Emergy from total**
58,464,381	6,738,173	11.53%	**2.61E+22**
59,433,266	6,991,823	11.76%	**3.28E+22**
59,562,258	6,903,762	11.59%	**5.50E+22**
60,661,346	7,205,013	11.88%	**6.19E+22**
60,450,411	7,016,095	11.61%	**4.83E+22**
57,288,259	6,417,502	11.20%	**2.26E+22**
58,082,455	6,615,266	11.39%	**2.75E+22**
58,281,786	6,762,631	11.60%	**2.27E+22**
57,710,917	6,756,698	11.71%	**2.74E+22**
58,201,967	7,003,802	12.03%	**3.29E+22**
58,123,954	7,314,164	12.58%	**3.14E+22**
57,913,096	7,607,577	13.14%	**3.89E+22**
58,169,310	7,869,869	13.53%	**4.11E+22**
57,415,948	7,972,230	13.89%	**4.61E+22**
57,485,437	8,270,104	14.39%	**4.83E+22**
57,503,577	8,508,731	14.80%	**5.86E+22**

Primary School	%	**Emergy from total**
35,150,362	60.12%	**1.36E+23**
34,438,749	57.95%	**1.61E+23**
34,012,434	57.10%	**2.71E+23**
33,534,561	55.28%	**2.88E+23**
33,282,663	55.06%	**2.29E+23**
31,733,198	55.39%	**1.12E+23**
31,694,497	54.57%	**1.32E+23**
31,705,528	54.40%	**1.06E+23**
31,005,341	53.73%	**1.26E+23**
30,490,476	52.39%	**1.43E+23**
29,826,627	51.32%	**1.28E+23**
29,187,602	50.40%	**1.49E+23**
28,571,512	49.12%	**1.49E+23**
27,931,210	48.65%	**1.62E+23**
27,691,478	48.17%	**1.62E+23**
27,348,080	47.56%	**1.88E+23**

Total Primary School %	**Total Prmary School Implemetation Emergy**
71.65%	**5.15E+21**
69.71%	**5.09E+21**
68.69%	**2.61E+22**
67.16%	**2.20E+22**
66.66%	**1.86E+22**
66.59%	**1.06E+22**
65.96%	**7.71E+21**
66.00%	**9.60E+21**
65.43%	**4.61E+21**
64.42%	**6.01E+21**
63.90%	**3.84E+21**
63.54%	**3.60E+21**
62.65%	**2.83E+21**
62.53%	**3.62E+21**
62.56%	**4.79E+21**
62.36%	**7.97E+21**

Secondary School	%	**Emergy from total**
13,055,219	22.33%	**5.06E+22**
14,065,761	23.67%	**6.59E+22**
14,573,309	24.47%	**1.16E+23**
16,468,328	27.15%	**1.41E+23**
15,470,550	25.59%	**1.06E+23**
13,887,412	24.24%	**4.90E+22**
14,247,966	24.53%	**5.91E+22**
13,859,606	23.78%	**4.64E+22**
13,623,016	23.61%	**5.53E+22**
14,025,716	24.10%	**6.58E+22**
13,971,431	24.04%	**6.00E+22**
13,931,830	24.06%	**7.13E+22**
14,032,417	24.12%	**7.32E+22**
13,599,807	23.69%	**7.87E+22**
13,604,291	23.67%	**7.94E+22**
13,495,116	23.47%	**9.30E+22**

Graduation School	%	**Emergy from total**
3,520,627	6.02%	**1.36E+22**
3,936,933	6.62%	**1.84E+22**
4,223,344	7.09%	**3.36E+22**
4,567,798	7.53%	**3.92E+22**
4,883,852	8.08%	**3.36E+22**
5,250,147	9.16%	**1.85E+22**
5,808,017	10.00%	**2.41E+22**
5,954,021	10.22%	**1.99E+22**
6,379,299	11.05%	**2.59E+22**
6,739,689	11.58%	**3.16E+22**
7,037,688	12.11%	**3.02E+22**
7,305,977	12.62%	**3.74E+22**
7,828,013	13.46%	**4.09E+22**
8,027,297	13.98%	**4.64E+22**
8,048,701	14.00%	**4.70E+22**
8,286,663	14.41%	**5.71E+22**

WORKERS FORMATION VIA DISTANCE TEACHING

Year	Total Primary School %	Total Prmary School Implemetation Emergy	Total Primary School DTC Usage	Total Primary School Access to Info	Total Primary School Info Flows	Total Primary School Emergy	Primary School EPSR
2002	**71.65%**	5.15E+21	8.12E+22	1.56E+22	6.05E+22	**1.62E+23**	**4.62E+15**
2003	**69.71%**	5.09E+21	1.11E+23	1.54E+22	6.28E+22	**1.94E+23**	**5.64E+15**
2004	**68.69%**	2.61E+22	6.78E+22	6.94E+22	1.63E+23	**3.26E+23**	**9.58E+15**
2005	**67.16%**	2.20E+22	5.55E+22	5.60E+22	2.17E+23	**3.50E+23**	**1.04E+16**
2006	**66.66%**	1.86E+22	4.54E+22	4.01E+22	1.73E+23	**2.77E+23**	**8.34E+15**
2007	**66.59%**	1.06E+22	2.65E+22	1.41E+22	8.33E+22	**1.35E+23**	**4.24E+15**
2008	**65.96%**	7.71E+21	2.22E+22	2.09E+22	1.08E+23	**1.59E+23**	**5.02E+15**
2009	**66.00%**	9.60E+21	1.77E+22	1.43E+22	8.73E+22	**1.29E+23**	**4.06E+15**
2010	**65.43%**	4.61E+21	1.71E+22	1.60E+22	1.16E+23	**1.53E+23**	**4.95E+15**
2011	**64.42%**	6.01E+21	2.33E+22	1.67E+22	1.30E+23	**1.76E+23**	**5.77E+15**
2012	**63.90%**	3.84E+21	1.65E+22	1.42E+22	1.25E+23	**1.59E+23**	**5.35E+15**
2013	**63.54%**	3.60E+21	1.70E+22	1.65E+22	1.51E+23	**1.88E+23**	**6.45E+15**
2014	**62.65%**	2.83E+21	1.45E+22	1.58E+22	1.57E+23	**1.90E+23**	**6.66E+15**
2015	**62.53%**	3.62E+21	2.16E+22	1.57E+22	1.67E+23	**2.08E+23**	**7.44E+15**
2016	**62.56%**	4.79E+21	1.71E+22	1.50E+22	1.73E+23	**2.10E+23**	**7.58E+15**
2017	**62.36%**	7.97E+21	2.87E+22	1.57E+22	1.95E+23	**2.47E+23**	**9.03E+15**

Year	Total Secondary School %	Total Secondary School Implemetation Emergy	Total Secondary School DTC Usage	Total Secondary School Access to Info	Total Secondary School Info Flows	Total Secondary School Emergy	Secondary School EPSR
2002	**22.33%**	1.60E+21	2.53E+22	4.86E+21	1.88E+22	**5.06E+22**	**3.88E+15**
2003	**23.67%**	1.73E+21	3.76E+22	5.24E+21	2.13E+22	**6.59E+22**	**4.69E+15**
2004	**24.47%**	9.29E+21	2.41E+22	2.47E+22	5.80E+22	**1.16E+23**	**7.97E+15**
2005	**27.15%**	8.88E+21	2.24E+22	2.26E+22	8.75E+22	**1.41E+23**	**8.59E+15**
2006	**25.59%**	7.13E+21	1.74E+22	1.54E+22	6.65E+22	**1.06E+23**	**6.88E+15**
2007	**24.24%**	3.87E+21	9.66E+21	5.15E+21	3.03E+22	**4.90E+22**	**3.53E+15**
2008	**24.53%**	2.87E+21	8.25E+21	7.78E+21	4.02E+22	**5.91E+22**	**4.15E+15**
2009	**23.78%**	3.46E+21	6.38E+21	5.15E+21	3.14E+22	**4.64E+22**	**3.35E+15**
2010	**23.61%**	1.66E+21	6.17E+21	5.77E+21	4.17E+22	**5.53E+22**	**4.06E+15**
2011	**24.10%**	2.25E+21	8.73E+21	6.23E+21	4.86E+22	**6.58E+22**	**4.69E+15**
2012	**24.04%**	1.44E+21	6.19E+21	5.33E+21	4.70E+22	**6.00E+22**	**4.29E+15**
2013	**24.06%**	1.36E+21	6.42E+21	6.24E+21	5.72E+22	**7.13E+22**	**5.12E+15**
2014	**24.12%**	1.09E+21	5.60E+21	6.09E+21	6.05E+22	**7.32E+22**	**5.22E+15**
2015	**23.69%**	1.37E+21	8.18E+21	5.94E+21	6.32E+22	**7.87E+22**	**5.78E+15**
2016	**23.67%**	1.81E+21	6.46E+21	5.69E+21	6.54E+22	**7.94E+22**	**5.84E+15**
2017	**23.47%**	3.00E+21	1.08E+22	5.92E+21	7.32E+22	**9.30E+22**	**6.89E+15**

Year	Total Graduation School %	Total Graduation School Implemetation Emergy	Total Graduation School DTC Usage	Total Graduation School Access to Info	Total Graduation School Info Flows	Total Graduation School Emergy	Graduation School EPSR
2002	**6.02%**	4.33E+20	6.82E+21	1.31E+21	5.08E+21	**1.36E+22**	**3.88E+15**
2003	**6.62%**	4.83E+20	1.05E+22	1.47E+21	5.97E+21	**1.84E+22**	**4.69E+15**
2004	**7.09%**	2.69E+21	7.00E+21	7.16E+21	1.68E+22	**3.36E+22**	**7.97E+15**
2005	**7.53%**	2.46E+21	6.22E+21	6.28E+21	2.43E+22	**3.92E+22**	**8.59E+15**
2006	**8.08%**	2.25E+21	5.50E+21	4.86E+21	2.10E+22	**3.36E+22**	**6.88E+15**
2007	**9.16%**	1.46E+21	3.65E+21	1.95E+21	1.15E+22	**1.85E+22**	**3.53E+15**
2008	**10.00%**	1.17E+21	3.36E+21	3.17E+21	1.64E+22	**2.41E+22**	**4.15E+15**
2009	**10.22%**	1.49E+21	2.74E+21	2.21E+21	1.35E+22	**1.99E+22**	**3.35E+15**
2010	**11.05%**	7.80E+20	2.89E+21	2.70E+21	1.95E+22	**2.59E+22**	**4.06E+15**
2011	**11.58%**	1.08E+21	4.19E+21	2.99E+21	2.34E+22	**3.16E+22**	**4.69E+15**
2012	**12.11%**	7.27E+20	3.12E+21	2.68E+21	2.37E+22	**3.02E+22**	**4.29E+15**
2013	**12.62%**	7.15E+20	3.37E+21	3.27E+21	3.00E+22	**3.74E+22**	**5.12E+15**
2014	**13.46%**	6.07E+20	3.13E+21	3.40E+21	3.37E+22	**4.09E+22**	**5.22E+15**
2015	**13.98%**	8.08E+20	4.83E+21	3.50E+21	3.73E+22	**4.64E+22**	**5.78E+15**
2016	**14.00%**	1.07E+21	3.82E+21	3.37E+21	3.87E+22	**4.70E+22**	**5.84E+15**
2017	**14.41%**	1.84E+21	6.63E+21	3.63E+21	4.50E+22	**5.71E+22**	**6.89E+15**

UEV reference

Note	Item	**Reference**
1	Concrete	Buranakarn (2003)
2	Steel	Buranakarn (2003)
3	Computer	Di Salvo, Agostinho (2018)
4	Electricity	Odum (1996)
5	Workbooks	this work
6	Labor	this work
7	Transportation	Buranakarn (2003)
8	Fuel (diesel)	Odum (1996)
9	Computer (students' units)	Di Salvo, Agostinho (2018)
10	Electricity	Odum (1996)
11	Information Teacher (1) --> Student (1%)	this work
12	Information Teacher (2) --> Student (1%)	this work
13	Information Teachers & Tutors (3) --> Student (1%)	this work
14	Information books --> students (10%)	this work
15	Information brought in by students (1) (10%)	this work
16	Information brought in by students (2) (10%)	this work
17	Information brought in by students (3) (10%)	this work