39

An Over Time Multi-Criteria Accounting of a Brazilian Bamboo Plantation

Luiz Ghelmandi Netto, Biagio F. Giannetti, Silvia H. Bonilla, Gloria Rótolo and Cecília M. V. B. Almeida

ABSTRACT

The environmental accounting of a Brazilian bamboo plantation was carried out with the application of five different methods based on the same set of inventory data, which provide a consistent exam of the system's performance and the comparability of calculated indicators. To obtain a comprehensive assessment, indicators built for larger regional or global scales were used in joint with local scale indicators. The bamboo plantation was evaluated for a period of 25 years, including implantation, adaptation and operation stages. It was concluded that multi criteria assessments aggregate results from methods, based on the same set of input data, and each method gives a measure of the effort to obtain a given input. However, each metric refers to a different effort, and though sometimes the resource use is associated with economic or environmental costs, the effort that each method considers must be taken into consideration.

INTRODUCTION

In several countries where the supply of wood raw materials is limited, bamboo is an important non-wood fiber resource used as alternative raw material to construction (Dongwei et al., 2011), reinforcing fibers (González et al., 2011, Mahdavi et al., 2012), paper production (Banavath et al., 2011, El Bassam, 1998), and other applications including nourishment (Kleinhenz and Midmore, 2001). Bamboo has also been proposed to provide bioenergy (Scurlock et al., 2000; Anselmo Filho & Badr, 2004). Most of the studies in the literature were carried out to quantify the biomass generated and converted into carbon and/or CO_2 by natural bamboo forests (Nakai et al. 2003; Sakai et al. 2006; Sakai & Akiyama, 2005). There are also evaluations of cultures rotation, in which bamboo is used to restore soil nutrients (Embaye et al. 2005; Christanty et al. 1996; Shanmughavel & Francis, 1996). Emergy synthesis was applied to compare the role of labor in a giant bamboo plantation. Results were compared with those obtained in China and Australia (Bonilla et al., 2010). A ranking based on emergy sustainability index (ESI) has shown that bamboo production is more favorable in China. However, when renewability embedded in labor is included, Brazil appears in the first place.

The evaluation of the matter and energy flows which sustain a bamboo plantation can be used to assess the efficiency of the production process, to describe the available natural resources rate of exploitation, and to provide a quantitative assessment of the impact on the environment. Several assessment methods are currently available, and each one can provide a particular insight in the performance of the production process under examination. Multi-criteria assessments are also popular (Ulgiati et al., 2006; Federici et al., 2008; Giannetti et al., 2008), since a variety of tools would enable producers to perform an integrated analysis of efficiency, sustainability, and feasibility of the production process. The choice of tools that make up the multi-criteria assessment has direct relationship with the parameters to be evaluated.

This paper presents the results of a multi-criteria analysis of a commercial bamboo plantation in Brazil. The integrated evaluation method was applied for joint assessment of CO_2 emissions, material intensity, cumulative exergy consumption, emergy synthesis and economic assessments. The analysis performed distinguishes the phases of implantation, adaptation and operation of the enterprise over 25 years.

METHOD

A farmer's manual published by João Santos Industrial Group (2000) was used to assess the bamboo plantation. The manual, directed to potential bamboo producers, discriminates against all costs associated with implanting and operating one hectare of a commercial bamboo plantation. For this, costs of three stages are considered: initial costs (implantation phase), adaptation costs and operating costs, covering a period of 25 years. The implantation phase covers the first three years of planting. During this period, the land is prepared to receive the bamboo plantation (cleaning, fertilizing, seeding), and the first cut of the culms is performed. The adaptation phase occurs between the 4th and 10th year of plantation, which is not yet fully adapted to the planting site. During this period, the use of agricultural inputs is intense, but the culms are old enough to be harvested at intervals of two years. From the11th to the 25th year in the operation phase, planting maintenance is done every four years, or every two harvests. At this stage, the bamboo plantation is fully adapted to the planting site (João Santos Industrial Group, 2000) and reaches its maximum annual production of 90 ton/ha.

A Multi-Criteria Assessment was adopted to evaluate the bamboo plantation over time. The selected assessment methods were CO_2 emissions (direct and indirect), material intensity, cumulative exergy consumption, emergy synthesis, and economic assessment. A brief description of each metric is given herein, but more specific details on the individual methods may be found in the references quoted in this text.

CO_2 Emissions: CO_2 released is divided into direct and indirect emissions. Direct emissions consist of the amount of CO_2 emitted by diesel exclusively used in the planting site due to workers' transportation, trucks used to carry culms, and seedlings preparation, among others. To obtain the CO_2 directly released into the atmosphere, the total diesel used was multiplied by its potential emission, 3.7 $kgCO_2/kg_{diesel}$ (Herendeen, 1998). Indirect CO_2 emissions are based on embodied energy analysis (Ulgiati et al. al., 2006). The embodied energy corresponds to all necessary energy to obtain the resources used in the system. Each input is multiplied by the Primary Energy Intensity (PEI) factor (Table 1), the total embodied energy is converted to oil equivalent (1 kgoe = 42 MJ) and, subsequently, to CO_2 emissions (3.22 gCO_2/goe) using appropriate conversion factors (Pellizzi, 1992; Brown and Ulgiati, 2002).

Material Intensity: This methodology assesses the environmental disturbance associated with the removal of material flows from their natural ecosystems (Wuppertal Institute for Climate, Environmental and Energy, 2003). Each input removed of its natural ecosystem causes disorganization in one or more parts of the biosphere, and material intensity accounts for materials directly and indirectly withdrawn to obtain a given resource used in a given system (Ulgiati et al., 2006). This metric considers that the Earth's biosphere is divided into four parts: biota, lithosphere, hydrosphere and atmosphere. The inputs of the system are multiplied by appropriate material intensity factors (MIF), to obtain the total material requirement (Table 1).

Cumulative exergy consumption: This metric account for the exergy of all natural resources consumed directly and indirectly by a given system, considering exergy requirements in the process as well as its supply chain (Szargut et al., 1988). Cumulative exergy is defined as the sum of the values of all the net primary exergy consumed in a series of processes leading from natural resources extracted from the environment to the investigated component (product or service) of a system. The conversion factor for calculating the CExC (Table 1) is the sum of two other factors: the amount of cumulative exergy from fuels and the cumulative amount of exergy from the raw material.

Emergy synthesis: This methodology accounts for the solar emergy of a flow or storage that is directly or indirectly required to generate the flow or storage (Odum, 1996). Emergy evaluations convert all process inputs, including energy of different types and energy inherent in materials and services, into emergy by means of UEV's (Unit Emergy Value). The UEVs for the bamboo plantation inputs are shown in Table 1.

Economic assessment: The economic assessment was based on the farmer's manual for bamboo planting and harvesting (Grupo Industrial João Santos, 2000).

Table 1. Factors used to calculate the inputs for each metric included in the Multi-Criteria Evaluation: CO_2 Emissions (Primary Energy Intensity - PEI); Material Intensity (Material Intensity Factor - MIF); Cumulative Exergy Consumption (Cumulative Exergy Consumption Factor - CExC); Emergy Synthesis (Unit Emergy Value - UEV).

Item	Unit	PEI (MJ/kg)	MIF [a] abiotic (kg/kg)	MIF [a] biotic (kg/kg)	MIF [a] Water (kg/kg)	MIF [a] Air (kg/kg)	CExC (MJ/kg)	UEV* (sej/unit)
Sun	J							1.00×10^{0} [g]
Wind	J							2.52×10^{3} [g]
Rain (potential energy)	J							1.76×10^{4} [g]
Rain (chemical energy)	J							3.06×10^{4} [g]
Geothermal energy	J							5.78×10^{4} [g]
Soil loss	J							1.24×10^{5} [g]
Labor	J							7.02×10^{6} [h]
Herbicide	kg	95.00 [b]	15.42	-	319.50	5.69	300,10 [d]	2.49×10^{3} [i]
Lubricants	kg	85.00 [b]	1.22	-	4.30	0.01	51.74 [e]	1.11×10^{5} [g]
Diesel	kg	50.40 [b]	1.36	-	9.70	0.02	53,20 [e]	1.11×10^{5} [g]
Hyperphosphate	kg	14.00 [b]	3.44	-	23.30	1.29	4.11 [e]	1.16×10^{12} [i]
Steel	kg	10.00 [b]	9.32	-	81.90	0.77	45,90 [e]	5.04×10^{12} [j]
Plastic/Rubber	kg	10.00 [b]	2.51	-	164.00	2.80	92.30 [e]	5.85×10^{12} [j]
Formicide	kg	55.00 [b]	7.61	-	16.20	1.08	7.69 [e]	1.68×10^{12} [g]
Lime	kg	1.67 [c]	5.48	-	39.30	2.19	0.34 [e]	1.68×10^{12} [g]
Hyperphosphate	kg	14.00 [b]	3.44	-	23.30	1.29	4.11 [e]	1.16×10^{12} [i]
Fertilizer NPK								
N	kg	75.00 [b]	3.45	-	44.60	1.82	53.99 [f]	7.07×10^{12} [i]
P_2O_5	kg	14.00 [b]	3,44	-	23,30	1,29	31.63 [f]	1.16×10^{13} [i]
K_2O	kg	10.00 [b]	11.32	-	10.60	0.07	6.31 [f]	4.97×10^{12} [i]

[a] *Wuppertal Institute for Climate, Environment and Energy (2003);* [b] *Pellizzi, G. 1992. Use of Energy and Labour in Italian Agriculture. Journal of Agriculture and Engineering Resources 52, p. 111-119.;* [c] *Romanelli, T. L. 2007. Sustentabilidade Energetica de um Sistema de Produção da Cultura de Eucalipto. p. 122. Doctorate Thesis – Escola Superior de Agricultura Luiz de Queiróz – ESALQ/USP. Piracicaba, Brazil.;* [d] *Patzek, T. W., Piementel, D. 2005. Thermodynamics of Energy Production from Biomass. Critical Reviews in Plant Sciences 24, p. 327-364.;* [e] *Szargut (1988);* [f] *Brehmer, B., Struik, P. C., Sanders. J. 2008. Using an energetic and exergetic life cycle analysis to assess the best applications of legumes within a biobased economy. Biomass and Bioenergy 32, p. 1175-1186.;* [g] *Odum (1996);* [h] *Bonilla, S. H., Guarnetti, R. L., Almeida, C. M. V. B., Giannetti, B. F., 2010. Sustainability assessment of a giant bamboo plantation in Brazil: exploring the influence of labour, time and space. Journal of Cleaner Production. 18. p. 83-91.;* [i] *Brown, M. T., Arding, J. 1991. Transformities. Working Paper. Center for Wetlands, University of Florida, Gainesville, USA.;* [j] *Brown, M. T., Buranakarn, V. 2003. Emergy indices and ratios for sustainable material cycles and recycle options. Resources, Conservation and Recycling 38, p. 1-22.*

* Global emergy base used: 15.83×10^{24} sej/yr (Odum et al., 2000).

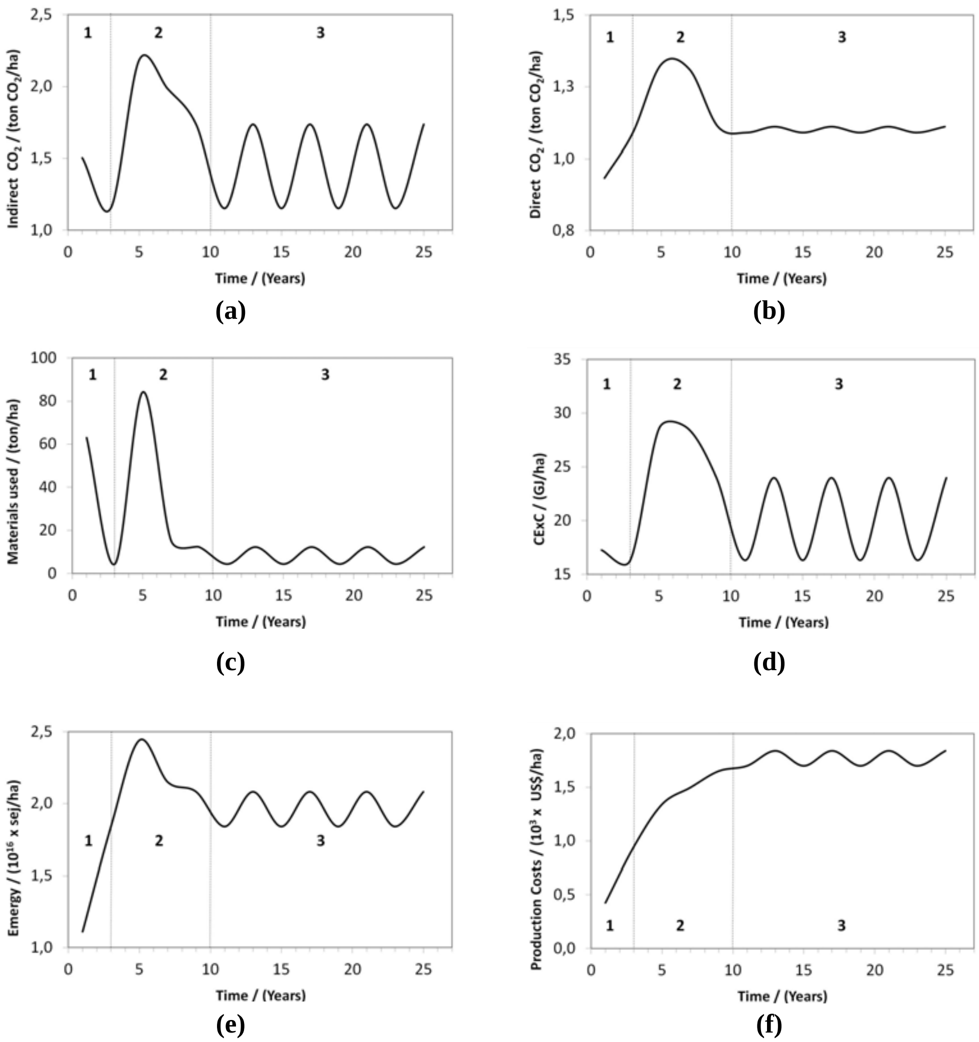

Figure 1. *Results of the multicriteria assessment of the bamboo plantation over 25 years: (1) Implantation phase; (2) Adaptation phase; (3) Operation phase. (a) Indirect CO_2 emissions, (b) Direct CO_2 emissions, (c) Material intensity, (d) Cumulative exergy consumption; (e) Emergy synthesis; and (f) Economic assessment.*

RESULTS AND DISCUSSION

Results of each method used in the study of bamboo plantation over 25 years are shown in Figure 1.

According to all methods used for environmental accounting, the higher consumption of materials and energy occurs in the adaptation phase, and among them, the material intensity metric is the only one that detects materials consumption higher than that observed for the operation phase. In the adaptation phase, direct and indirect emissions of CO_2 are also the highest within the overall period. The economic assessment shows different trend, according to which the costs increase over time.

Table 2. Percentages of each methodology key inputs considered in the multi criteria assessment.

	Indirect CO_2 emissions	Material Intensity	Cumulative Exergy Consumption	Emergy Synthesis	Economic Assessment
Implantation	**Diesel - 78%** Agricultural Inputs - 15%	Diesel - 9% **Agricultural Inputs - 69%**	**Diesel - 86%** Agricultural Inputs - 5%	**Labor - 55%** Rain - 17% Diesel - 7% Agricultural Inputs - 12%	**Labor - 68%** Diesel - 13%
Adaptation	**Diesel - 66%** Agricultural Inputs - 28%	Diesel - 11% **Agricultural Inputs - 69%**	**Diesel - 66%** Agricultural Inputs - 28%	**Labor - 58%** Rain - 19% Diesel - 6% Agricultural Inputs - 7%	**Labor - 58%** Diesel - 18%
Operation	**Diesel - 80%** Agricultural Inputs - 20%	Diesel - 34% **Agricultural Inputs - 37%**	**Diesel - 79%** Agricultural Inputs - 18%	**Labor - 66%** Rain - 18% Diesel - 7% Agricultural Inputs - 5%	**Labor - 63%** Diesel - 20%

Agricultural Inputs = Formicide + Lime + Hyperphosphate + Fertilizer NPK

Considering the procedures established for each criterion, one can separate the particular inputs discriminated by each metric in the evaluation of the bamboo plantation. Each method evaluates the system performance according to its own point of view, and according to the key inputs that are considered in the evaluation procedures. Inputs that correspond to each period observed in curves shown in Figure 1 are detailed in Table 2. Direct CO_2 emissions only account for diesel and were not included.

Table 2 shows that all methods identify the impact caused by the upstream use of diesel. Depending on the rules established for each assessment method, this impact has greater or lesser contribution to the total impact. In the case of indirect CO_2 measurement, the impact is directly translated into emissions that can be added to those detected by direct measurements. Diesel consumption is also responsible for most of the recorded cumulative exergy. Material intensity and emergy assign to diesel a contribution of less than 20% of the total impact, while for indirect CO_2 and CExC this contribution is greater than 60%. In the case of materials intensity, the upstream impact of diesel translates into indirect water used to obtain this input, which is lower than the water used to obtain agricultural inputs (especially limestone). For the emergy synthesis, diesel contribution is reduced as other inputs, not accounted for by previous approaches (labor and natural resources), are considered in the primary data set. It is intriguing to note that economic assessment does not recognize agricultural inputs costs as significant, but according to the farmer’s manual (João Santos Industrial Group, 2000) fertilizers consume only a small portion of the total budget.

Except for the economic evaluation and emergy synthesis, which include labor as primary inputs, agricultural inputs appear as the secondly leading cause of upstream impact. It is important to note that, according to the indirect CO_2 measurements, this impact translates into emissions of diesel used for obtaining these inputs. For CExC, the impact refers to the energy expended to make them, and in the case of materials intensity, the impact is related to the water indirectly used for obtaining limestone and fertilizers. According to the results of the two methodologies that include human labor in the primary data, the economic costs and the cost of labor to the biosphere are causes of major impact. Finally, the use of natural resources accounted for only by the emergy synthesis contributes with a significant share of 17% of the resources appropriated by the bamboo plantation.

CONCLUDING REMARKS

An overtime multi criteria assessment was applied in order to evaluate a Brazilian bamboo plantation based on the same set of input data. The objectives were to provide the basis for improving the system performance, and discussing the role of each assessment method to achieve this goal. Multi criteria assessments need that many different aspects are taken into account. Some of them, primarily technical, relate to the local scale at which the activity occurs. Other technological, economic and environmental aspects affect larger temporal and spatial scales in which the system is inserted. These effects require a thoughtful evaluation of the relation between the system and its surroundings, so that concealed or potential causes of inefficiency and impact are clearly identified.

With regard to process improvements, the direct and indirect CO_2 measurements call for actions to minimize the use of diesel and agricultural inputs. The same result is obtained using cumulative exergy consumption method. When it comes to water use, in a larger temporal and spatial scale, materials intensity points to the reduction of the use of limestone and fertilizers. However, this would not be one of the farmer's concerns, if only an economic evaluation is done, since fertilizers do not contribute significantly in their budget. Depending on the metric used, the farmer has a different perception of the system. When he employs the economic evaluation, he can distinguish clearly that labor and diesel are the main production costs, but he fails to recognize the external environmental costs that are identified by assessments of CO_2 emissions, cumulative exergy consumption, material intensity and emergy.

As regards the scope of the metrics used in multi criteria evaluation, it is observed that the combination of two or more metrics allows more judicious actions with respect to the use of inputs. If the main concern is atmospheric emission, accounting for the direct and indirect CO_2 provides a satisfactory indicator. If the concern is the use of water, emergy synthesis in combination with material intensity can provide a basis for future actions. As expected, the economic assessment is more limited, since the budget is subjected to the planting location, and to market oscillations.

Multi criteria assessments aggregate results from methods, based on the same set of input data, and each method gives a measure of the effort to obtain a given input. However, each metric refers to a different effort, and though sometimes the resource use is associated with costs (economic or environmental), one should remember the effort that each method considers. The economic effort refers to the money to acquire the resources. Exergy is related to the effort to produce materials and fuels used, and materials intensity refers to efforts associated and the amount of materials exploited along the production chain. On the other hand, CO_2 emissions refer to greenhouse gases release, and is related to the effort that the atmosphere will make to compensate its adiabatic condition.

Emergy synthesis measures the effort (work done by the biosphere) to obtain resources employed. It evaluates environmental costs (resources appropriation for production), but also gives a measure of the resource quality related to work done by Nature to supply this resource. Locally, emergy identifies that rain is an essential resource for production. It also recognizes labor as a fundamental resource, but, differently of classic economic assessment, labor is an asset rather than a cost. Labor is identified as a valuable resource that can lead to sustainable production system, if its support is done under conditions of use of renewable resources.

The emergy synthesis is the method that covers the largest number of inputs required for the correct functioning of the plantation activities. It also has the advantage of considering a temporal and spatial scale larger than that in which the planting is installed. Thus, it appears to be the only method that can be used alone with reliable results.

ACKNOWLEDGEMENTS

This study had financial support from 'Vice-Reitoria de Pós-Graduação e Pesquisa' of 'Universidade Paulista-UNIP'.

REFERENCES

Anselmo Filho, P., Badr, O. 2004. Biomass resources for energy in North-Eastern Brazil. Applied Energy. 77. p. 51-67.

Banavath, H. N., Bhardwaj, N. K., Ray, A. K. 2011. A comparative study of the effect of refining on charge of various pulps. Bioresource Technology, 102 (6), p.4544-4551

Christanty, L., Mailly, D., Kimmins, J.P. 1996. “Without bamboo the land dies”: Biomass, litterfall, and soil organic matter dynamics of a Javanese bamboo talun-kebun system. Forest Ecology and Management 87, p. 75-88.

Dongwei, Y., Hongwei, T., Yingjun, R. 2011. A future bamboo-structure residential building prototype in China: Life cycle assessment of energy use and carbon emission. Energy and Buildings, 43 (10), p.2638-2646.

El Bassam N. 1998. Energy plant species: their use and impact on environment and development. London. James and James. 321 pp.

Embaye, K., Weih, M., Ledin, S., Christersson, L. 2005. Biomass and nutrient distribution in a highland bamboo forest in southwest Ethiopia: implications for management. Forest Ecology and Management 204, p. 159-169.

Federici, M., Ulgiati, S., Basosi, R. 2008. A thermodynamic, environmental and material flow analysis of the Italian highway and railway transport systems. Energy 33, p. 760-775.

Giannetti, B. F., Bonilla, S. H., Silva, I. R., Almeida, C. M. V. B. 2008. Cleaner production practices in a medium size gold-plated jewelry company in Brazil: when little changes make the difference. Journal of Cleaner Production 16, p. 1106-1117.

González, D., Santos, V., Parajó, J. C. 2011. Manufacture of fibrous reinforcements for biocomposites and hemicellulosic oligomers from bamboo. Chemical Engineering Journal, 167 (1), p.278-287

Herendeen, R. 1998. Ecological Numeracy: quantitative analysis of environmental issues. Jonh Wiley and Sons, Canada.

João Santos Industrial Group. 2000. Bambu, do plantio à colheita – Manual do fazendeiro florestal. SINDIFLORA. p. 1-33.

Kleinhenz, V., Midmore, D. J. 2001. Aspects of bamboo agronomy. Advances in Agronomy, 74, p.99-153

Mahdavi, M., Clouston, P. L., Arwade, S. R. 2012. A low-technology approach toward fabrication of Laminated Bamboo Lumber. Construction and Building Materials, 29, p.257-262

Nakai, Y., Kitamura, K., Suzuki, S., Abe, S. 2003. Year-long carbon dioxide exchange above a broadleaf deciduous forest in Sapporo, Northern Japan. Tellus 55B, p. 305-312.

Odum H. T. 1996. Environmental accounting – Emergy and environmental decision making. John Wiley & Sons Ltd. p. 370.

Odum, H. T., Brown, M, T., Brandt-Williams, S. 2000. Handbook of Emergy Evaluation: A Compendium of Data for Emergy Computation Issued in a Series of Folios. Folio #1 - Introduction and Global Budget. Center for Environmental Policy, Environmental Engineering Sciences, Univ. of Florida, Gainesville, p. 16.

Sakai, T., Akiyama, T. 2005. Quantifying the spatio-temporal variability of net primary production of the understory species, *Sasa senanensis*, using multipoint measuring techniques. Agricultural and Forest Meteorology 134, p. 60-69.

Sakai, T., Akiyama, T., Saigusa, N., Yamamoto, S., Yasuoka, Y. 2006. The contribution of gross primary production of understory dwarf bamboo, *Sasa senanesis*, in a cool-temperate deciduous broadleaved forest in central Japan. Forest Ecology and Management 236, p. 259-267.

Scurlock, J. M. O., Dayton, D. C., Hames, B. 2000. Bamboo: an overlooked biomass resource?. Biomass and Bioenergy 19. p. 229-244.

Shanmughavel, P., Francis, K. 1996. Above ground biomass production and nutrient distribution in growing bamboo (Bambusa bambos (L) voss). Biomass and Bioenergy 10, p. 383-391.

Szargut, J., Morris, D. R., Steward, F. R. 1988. Exergy analysis of thermal, chemical and metallurgical processes. Hemisphere Public Corporation. p. 332.

Ulgiati, S., Raugei. M., Bargigli. S. 2006. Overcoming the inadequancy of single-criterion approaches to Life Cycle Assessment. Ecological Modelling 190. p. 432-442.

Wuppertal Institute for Climate, Environment and Energy. Calculating MIP’s, resources productivity of products and services. 2003.

Website: http://www.wupperinst.org/uploads/tx_wibeitrag/MIT_v2.pdf.