UNIVERSIDADE PAULISTA – UNIP

DOCTORATE PROGRAM IN INDUSTRIAL ENGINEERING

STUDY OF ENVIRONMENTAL SUSTAINABILITY OF ABC PAULISTA USING EMERGY SYNTHESIS

FÁBIO SEVEGNANI

SÃO PAULO

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1. Desenvolvimento urbano. 2. Disponibilidade de recursos naturais. 3. Síntese em emergia 4. Contabilidade ambiental.

I. Título.

DEDICATION

I dedicate this work to my parents, Francisco and Isabel that have always inspired me and gave me support. Also, a special dedication to my lovely wife Fernanda that was by my side in all the moments and a particular thank for the patience and understanding during the time I was away.

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"This most beautiful system of the sun, planets and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being."

(Isaac Newton)

SUMMARY

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RESUMO

Este trabalho aplica a metodologia da síntese em emergia para avaliar a sustentabilidade dos municípios que formam o ABC Paulista, através de uma abordagem capaz de reunir aspectos econômicos e ambientais. O ABC Paulista é um grupo de três municípios: Santo André (SA), São Bernardo do Campo (SBC) e São Caetano do Sul (SCS), que é parte da Grande São Paulo. O ABC Paulista é uma importante área industrial, tecnológica e de moradia que dá suporte para a Grande São Paulo. As indústrias automobilística e química são a principal atividade econômica neste sistema urbano. Apesar de serem municípios vizinhos, algumas diferenças ambientais e econômicas são observadas entre eles. Indicadores em emergia foram calculados e os resultados foram interpretados usando o diagrama emergético ternário. Os resultados mostram que o ABC Paulista, bem como seus municípios separadamente, são altamente dependentes de recursos importados de fora de seus limites, sendo eles não sustentáveis em longo prazo.

Palavras-chave: desenvolvimento urbano, disponibilidade de recursos naturais, síntese em emergia, contabilidade ambiental.

ABSTRACT

This work applies the emergy synthesis methodology to evaluate the environmental sustainability of the municipalities that form ABC Paulista, through an approach capable to gather economic and environmental aspects. ABC Paulista is a group of three municipalities: Santo André (SA), São Bernardo do Campo (SBC) and São Caetano do Sul (SCS), which is part of Greater São Paulo. ABC Paulista is an important industrial, technological and housing area that gives support to Greater São Paulo. Automotive and chemical industries are the leading economic activity in this urban system. Despite being neighbor municipalities, some environmental and economic differences are observed between them. Emergy indices were calculated, and results were interpreted with the use of the ternary emergetic diagram. Results show that ABC Paulista, as well as the three municipalities separately, are highly dependent on imported resources from outside its boundaries, being them not sustainable in the long term.

Key words: urban development, availability of natural resources, emergy synthesis, environmental accounting.

1. Introduction

For many centuries society has expanded based on the use of energy from non-renewable resources - those that nature is not capable to replace within the window time of the society's development.

The Demographia World Urban Areas annually reports the inventory for all nearly 850 identified urban areas (urban agglomerations or urbanized areas) in the world with 500,000 or more population.

The total population of urban areas in 2012 was estimated at nearly 1.8 billion, 48 % of the world urban population (Demographia World Urban Areas, 2012). By the year 2030, 60% of the world population will probably be urban, thus generating a huge change of lifestyle, land use, demand for energy and other resources, and environmental pressure (Ascione et al., 2009).

The urban settlements concentrate emergy flows that support their economy into reduced areas, with economic development accelerated by the use of cheap fossil fuels, electricity, interacting with the resources that support the human life (water, air and land). The materials, energy, and food supplies are brought into cities and transformed within the cities. In addition to the products and wastes sent out from the cities, and from an ecosystem’s perspective, cities are often unsustainable because of their dependence on these flows. As cities draw more and more resources from distant areas, they also accumulate large amounts of materials that become urban assets (buildings and infrastructure). Hence, a central point is how to evaluate the sustainable development ability of those ecological-economic systems in a quantitatively manner.

A metropolitan area is different from an urban area. A metropolitan area includes rural (non-urban) territory or area of discontinuous urban development. A metropolitan area is a large population center consisting of a large metropolis and its adjacent zone of influence, or of more than one closely adjoining neighboring central cities and their zones of influence. These agglomerations are centers of various activities, which have an impact on the biosphere as primary consumers of resources and environmental services supplied from outside their boundaries. Cities need areas, people, materials, information and other resources for the various activities they held, depending on a greater or lesser extent on activities undertaken in other regions. Among these activities, one can consider the production of food, fuel and raw materials, water supply and treatment, solid waste storage systems, people training, and other activities that cannot be developed within the limits of the municipality.

Sahely et al., (2003) point out that research on urban metabolism can contribute to solving urban ecological and environmental problems by highlighting the demands that the urban ecosystem places on various resources and the pressure of discharged wastes place on the environment in and around the urban ecosystem. The existence and maintenance of a city and its internal structure depend on the flow of goods and services into, out of, and throughout that city (Huang and Chen, 2009). Hence, there must be a steady flow of energy, coming from various locations of the biosphere, in the form of materials, people, information and others crossing the boundaries of the municipality. According to Ascione et al. (2009), a system driven by outside resources (be they renewable or not) is never “sustainable”, although it can somehow be stable for a relatively long time, depending on the stability of the support flows from outside. The urban population growth generates several changes in life style, land use, energy demand and consequent environmental pressure. In this way, studies related to environmental sustainability of urban systems and the availability of natural resources are of major importance.

Emergy evaluation of states, nations, and their resource basis give large-scale perspective to appraisal of environmental areas and helps select policies for public benefit (Odum, 1996). Through emergy synthesis, it is possible to distinguish exchanges between the municipality and the "external environment" in order to assess its sustainability, and to estimate the real wealth of a region with a more pragmatic approach than the vision purposed by the economic evaluation of Gross Domestic Product (GDP) or the social assessment performed by the Human Development Index (HDI). Since cities are particular ecosystems (Odum et al., 1995), there is a need for a more comprehensive view of resources and environmental services provided by the biosphere.

The ABC Paulista is an important industrial, technological and housing area that gives support to Greater São Paulo. This group of municipalities is located in the state of São Paulo in the southeast region of Brazil, and it is also part of the Greater São Paulo that is composed by São Paulo city and other 39 municipalities (Fig. 1).

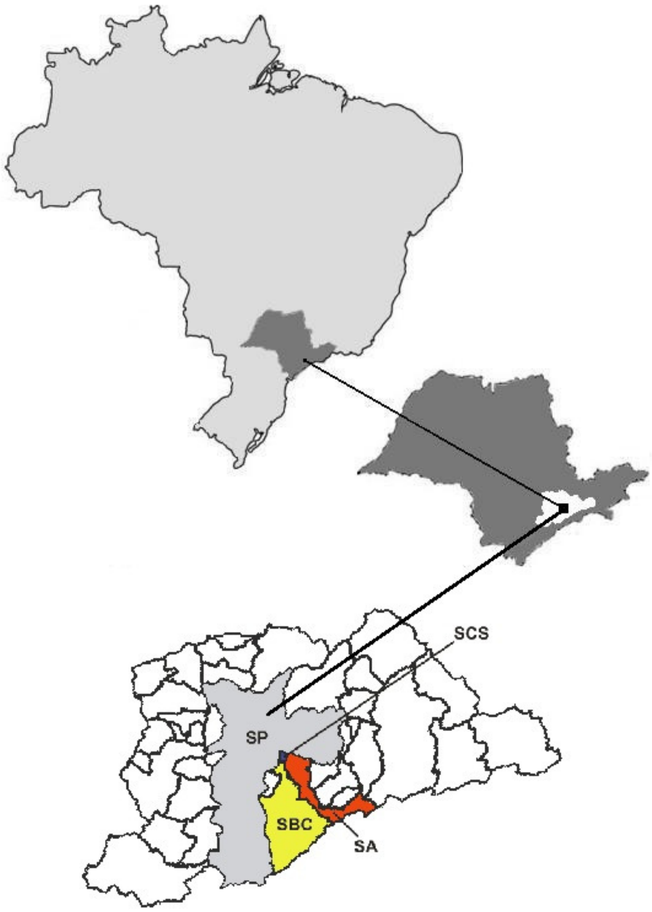

Fig. 1 – Location of ABC Paulista in Greater São Paulo, state of São Paulo, and Brazil

The economic development of the ABC Paulista was primarily due to the presence of the automotive industry. This industry has started around 1920 and still remains as a significant industrial activity. The chemical industry is also an important sector, especially in Santo André. Regarding the GDP of 2009, the municipalities of ABC Paulista contributed with 4.8% of the GDP of the state of São Paulo. When it comes to nationwide, ABC Paulista contributed with almost 3% of the GDP of Brazil in the same year. São Bernardo do Campo occupied 13th position and Santo André 29th position regarding Brazil's GDP rank (IBGE, 2009). These numbers show the importance of ABC Paulista in the economy of the state of São Paulo and also in Brazil. The region is also an important supplier of natural resources to other cities of Greater São Paulo. The Billings dam, partially located in Santo André and São Bernardo do Campo is one of the main water reservoirs that supply water to Greater São Paulo.

From the perspective of regional development, these grouped cities share the similar climate condition, infrastructure facilities, and the relative advantage of clustering of industrial activities, but they also compete for local resources and market. The sustainability of regional development with respect to urban agglomeration is much associated with the performance of individual cities and their interactions with each other (Cai et al., 2009). Reciprocity between subsystems with competing objectives is viewed today as a crucial determinant of system sustainability (Higgins, 2003).

Table 1 shows main information about the ABC Paulista divided in its municipalities and as a whole.

Table 1 – Main information about the municipalities of ABC Paulista

	Municipality			
	Santo André	São Bernardo do Campo	São Caetano do Sul	ABC
Area[a] (km^2)	175	406	15	596
Population[a] (inhabit.)	673,396	810,979	152,093	1,636,468
GDP[a] (10^3 USD)	7,354,801	14,467,883	4,460,101	26,282,785
GDP[(*)] per capita[a] (USD)	10,921.96	17,840.02	29,324.82	16,060.68
HDI[(**) a,b]	0.835	0.834	0.919	-
Percentage of green area[c]	35.78%	46.97%	0.14%	42.50%
Total in green area (km^2) [c]	62.62	190.70	0.02	253.33
Latitude[a]	-23° 39' 50''	-23° 41' 38''	-23° 37' 23''	-
Longitude[a]	-46° 32' 18''	-46° 33' 54''	-46° 33' 04''	-
Height (m)[a]	755	762	744	-

[a] IBGE (2009); [b] UNPD (2000); [c] Sec. Meio Amb. (2009)

(*) GDP is the total for final use of output of goods and services produced by an economy, by both residents and nonresidents, regardless of the allocation to domestic and foreign claims (UNPD, 2000).
(**) The concept of Human Development is the based in the idea that to study only the economic dimension is not enough to measure life quality. Other characteristics like social, cultural and politics have also to be observed. The HDI intends to be a general and synthetic measure of the human development. Besides computing the per capita GDP, after correcting it by the purchase power of each country, the HDI also considers other components: the life expectancy and education.

This work was developed together with the study of Brazil and its states (Demétrio, 2011) within the doctorate program in industrial engineering of

Universidade Paulista in the research line Cleaner Production and Industrial Ecology. The study applies the emergy synthesis to the group of three municipalities named ABC Paulista that is composed of: Santo **A**ndré (SA), São **B**ernardo do Campo (SBC) and São **C**aetano do Sul (SCS).

2. Bibliographic Review

2.1 Emergy applied to urban systems

The emergy synthesis of urban systems has been applied since the 80s by several authors to study regional systems at smaller or larger scale. Brown (1980) has used data on regional and national patterns of landscape organization to test theories of energy flow control of hierarchy. The author developed simulation models to quantitatively relate ideas of mechanism and energetics to web structure, spatial pattern, and spectral distributions observed in the hierarchies of humanity and nature. The study was applied to urban areas, watersheds and counties and comparisons were made with US national patterns and other types of hierarchies. Simulations tested were: stocking, harvesting and pulsing energy source. It is pointed out that the simulation of perturbation responses suggests that stability is enhanced by hierarchic organization. The theory of energy control of hierarchically organized systems provided suggestions for determining carrying capacity of human activity in regions, and possible effects on the organization of the landscape with decreasing availability of fossil fuels. The author suggests that regional landscapes of man and nature form a hierarchy with qualities measurable from their embodied energy, and that spatial distribution of quality, value, and human activity may be predicted from energy distributions.

Giannetti et al. (2006) proposed a graphic tool called ternary diagram to assist environmental accounting and environmental decision-making based on emergy analysis. The authors pointed out that the use of ternary diagrams permits the use of the phase diagram properties to assess the dependence of the system upon renewable and non-renewable inputs. Later this tool was applied by Almeida et al. (2007) by means of five examples of application. One of the examples was the urban ecosystems of Taipei that was studied by Huang and Odum (1991). In 2010 Giannetti et al. made a comparison of the emergy accounting with well-known sustainability metrics using the case study of Southern Cone Common Market, Mercosur. In this study, the ternary diagrams were also applied to show each country that belongs to Mercosur.

Pulselli et al. (2007a) proposed an integrated framework to investigate human-dominated systems and provided a basic approach to urban and regional studies in which the multiple interactions between economic and ecological processes are considered as a whole. This integrated framework was applied to the Province of Cagliari, which is composed by 109 municipalities, in Italy. Results have shown a non-homogeneous spatial distribution of emergy flows throughout the region, suggesting the way ecosystem functions are affected and restructured by the human economy. Based in the emergy evaluation of the region, these authors observed that cities and industrial districts, where population density is high and many transformation processes occur, function as nodes with the highest levels of organization and the highest intensity of emergy flows. Areas with low emergy use function as reservoirs of natural resources and feed the activity of the highly structured nodes. Finally, authors concluded that the emergy characteristics of different land uses have implications for planning and management, for example spatial allocation and arrangement of land use and infrastructures to redistribute ecosystem functions and emergy flow patterns.

Later, Pulselli et al. (2008) have shown how different methods can be integrated in order to provide an organic evaluation of the environmental sustainability at the territorial level. The paper focus in the description of the SPIn-Eco Project, a multiyear (2001–2004) research program with the purpose of assessing the environmental conditions and the relative level of sustainability of the Province of Siena and its 36 municipalities. It is described as a thorough analysis of the state of the territorial system through a set of sustainability indicators.

Lei at al. (2008) performed an emergy analysis of Macao, using data from 2004, providing a holistic view of this complex urban system. The concepts of net emergy and net emergy ratio were used to assess the real wealth of Macao and then compared to the emergy results for Taipei (2002), Zhongshan (2000), Miami (1990) and San Juan (1992). These authors proposed a modified emergy framework that reflects holistic processes at the level of a whole country, and have added a net emergy frame. It was concluded that the Net Emergy Ratio (NER) values for the studied cities were all too high for sustainability. Previous studies, that have used the ESI indicator, were criticized due to the fact that ESI is an analytical tool that cannot explain differences among cities. The NER index used in the study is explained to be a more realistic indicator than the ESI because it accounts for the material and monetary emergy exchanges with the external system.

Still in 2008, Lei and Wang applied the approach of emergy synthesis to investigate and characterize the urban evolution and city development that have occurred in Macao from 1983 to 2003. The emergy flow related to tourism was tracked and analyzed to measure its contribution to Macao. The authors present trends in major emergy components and related parameters from 1983 to 2003 and show that by relying on an attractive gambling industry and an imbalance between imports and exports, Macao has absorbed large amounts of emergy through negative entropy inflows to support not only its survival, but also its booming development.

Ascione et al. (2009) performed an evaluation of the resource basis of the city of Rome using Emergy concepts. The main goal of the paper was to help understanding the direct and indirect environmental work that supports the urban development, and which portion of urban system assets, population and activity would be sustainable by relying solely on locally available renewable resources. The emergy assessment is performed focusing on the total emergy demand of the city, benchmarking databases (e.g., total gasoline consumption, total natural gas, total amount of construction materials, total amount of food used, total water, fertilizers, etc.), providing a reference picture for detailed investigation of specific production and consumption sectors as well as urban zones. According to the authors, Rome is a city sustained mainly by imports of non-renewable resources and a large fraction of goods and commodities (most of which construction materials). The emergy associated to fuels and electricity (for transportation and domestic sectors) is also a large share of the total. The results shown in the emergy tables indicate that local flows (be they renewable or not) are negligible (less than 2%) compared to imported emergy flows (98%). The largest input category is represented by the flow of imported goods and commodities (42% sej/sej, out of which construction material correspond to 75% sej/sej), followed by imported fuels and electricity (21% sej/sej). Water and food items account for about 13.6% of total emergy use. These authors underline the importance of a sensitivity analysis to identify main flows that are subject to create significant changes even having a small value change.

When it comes to emergy-based indicators, the authors made a comparison Rome and Italy. In particular, the small value of the EYR of Rome (1.02) shows that the city is simply a consumer system, without any possibility of relying on local resources while the Italian system as a whole (1.29) relies much more on local resources (agriculture, minerals, hydroelectricity, etc.). The ELR calculated for Rome (60.43) is four times higher than that of Italy, indicating that the urban system is very far from being in equilibrium with the surrounding environment. Finally, these authors show how it is possible to use the results for policy making and make comparisons of the results obtained for Rome with the results of other cities: Taipei, Macao and San Juan.

In 2009 Zhang et al. did a preliminary emergy-based comparison analysis for three typical mega cities in China, Beijing, Shanghai and Guangzhou, in four perspectives including emergy intensity, resource structure, environmental pressure and resource use efficiency. These authors proposed a new index of non-renewable emergy/money ratio to indicate the utilization efficiency of the non-renewable resources. The results of the emergy-based comparison have shown that the three cities exhibited similar overall trends of increase of total emergy. Among the three cities Shanghai achieved the highest level of economic development and non-renewable resource use efficiency, meanwhile, lower proportion of renewable resource use and higher environmental pressure were observed in Beijing and Guangzhou.

Zhang et al. (2009a), developed an indicator system for evaluating the urban metabolism based on the city's metabolic processes, and demonstrated the use of this indicator system in a case study of Beijing (China) by analyzing the metabolic fluxes, intensity, efficiency, and pressure in the urban metabolic system. It was used a historical series of emergy indicators to assess the evolution of the urban metabolic system from 1990 to 2004. A comparison is made between Beijing and other four Chinese cities: Shanghai, Guangzhou, Ningbo and Baotou. These authors concluded that during the period of study, Beijing's metabolic flux, metabolic intensity, and metabolic density increased significantly and the metabolic efficiency increased at a linear average annual rate of 12%. Despite the increase of metabolic efficiency and some improvements, the metabolic structure remained deficient at the end of the study period because of excessive dependence on non-renewable resources and natural resources obtained from outside the city. The comparison with the four other Chinese cities has shown that Beijing had the highest metabolic fluxes and density, but had relatively low metabolic efficiency and relatively high metabolic intensity. It is pointed out that the evaluation of these metabolic indicators revealed the weak links in the urban metabolic system, and this can help choosing measures to improve the sustainability of the city's metabolic health. In the same year, Zhang et al. proposed, based on ecological thermodynamics, an indicator system to evaluate the fluxes, stocks, and efficiency of the urban material metabolism using emergy analysis. Also, a new model for the urban material metabolism was proposed to define the production possibility curve using a wealth index (WI) and an ecological efficiency index (EEI). The validation of this model was done for the cities of Beijing, Shanghai, Tianjin, Chongqing, Guangzhou, and Shenzhen.

Su et al. (2009) proposed a framework of evaluation model and related indicators based on emergy to assess the urban ecosystem health state with respect to the energy and materials metabolism. The authors combine the emergy-based indicators with the essential components of the urban ecosystem health the framework of emergy-based urban ecosystem health indicator ($UEHI_{em}$). These methods are applied to assess the heath of 20 typical Chinese cities in view of vigor, structure, resilience, ecosystem service function maintenance, and environmental impact to evaluate the health state in a biophysical way.

Liu et al. (2009) have performed the assessment of the urban ecosystem health of Baotou in China using emergy concepts confronted with the traditional ecosystem health assessment. By means of this case study, it is proposed a new emergy-based index for urban ecosystem health assessment. The assessment results of Baotou city are compared with those of five other cities including Beijing, Guangzhou, Hong Kong, Ningbo and Macao. These authors explain the concept of the new indicator named emergy-based urban ecosystem health index (EUEHI). This new indicator is explained to be able to support the temporal study of the urban ecosystem health of the same city and comparisons of ecosystem health levels among different cities. The higher EUEHI is the healthier the urban ecosystem is. It was concluded that due to an emphasis on the resource structure adjustment and utilization efficiency, Baotou has obtained a better organizational structure and ecosystem service function for the integrated urban ecosystem during 2000–2004, despite the larger environment pressure and lower ecosystem recovery capability. The comparison of Baotou city with the other five Chinese cities based on emergy-based sustainability index (ESI), emergy index of sustainable development (EISD) and EUEHI, shows that Baotou city in 2004 is still at a relatively low urban ecosystem health level.

Pulselli (2010) applied the emergy accounting combined with a geographic information system for monitoring the resource use in the Abruzzo region in Italy. The geographic information system allowed the author to represent the spatial distribution of the emergy flows throughout the region being possible cartographic basis visualization. The emergy flows according to the activities developed in the local communities showed different levels of environmental load. The author concluded that the cartographic basis has showed a general organization configuration highlighting the level of dependence of various sub-systems not only on the natural environment but also on a more or less intense activity of exchanges with other systems. The author finalizes pointing out that a constant monitoring of emergy flows in the future and their elaboration through geographic information system would provide information about current trends of environmental resource use. Sequences of maps would dynamically represent the evolution of a territorial system with its activities and behaviors over time.

Later Ulgiati et al. (2011) used the data of Rome (Ascione et al., 2009) and the data of the agricultural sector of the Campania Region (Zucaro et al., 2010) to propose and apply the idea of a complexity indicator based on the diversity of energy and resource use by a system called diversity ratio (ΔSD). These authors point out that the diversity ratio it is not meant to be an indicator of reliance on renewable or non-renewable resources, nor it is suggested as an indicator of sustainability. A high source diversity ratio means that the system relies on a larger set of resource options. This makes it more likely to develop complex structures and therefore more resilient in the face of fluctuations.

Zhang et al. (2011) analyzed Beijing's urban metabolic system using emergy synthesis to evaluate its environmental resources, economy, and environmental and economic relations with the regions outside the city during

14 years of development. The authors compared Beijing's emergy indices with those of five other Chinese cities and of China as a whole to assess Beijing's relative development status. The authors concluded in this new analysis that Beijing's socioeconomic system is not self-sufficient and depends majorly on external environmental resources. Its GDP is supported by a high percentage of emergy purchased from outside the city. It is pointed out that, during the study period, Beijing's urban system has shown an increasing dependence on external resources for its economic development. The authors concluded that Beijing's loading and pressure on the ecological environment are continuously increasing, accompanied by continuously increasing human emergy consumption.

Chen et al., 2011 have presented a conceptual model that proposes a new way to quantify ecological and economic interactions between two cities. In the emergy diagram, the authors divide the urban system into urban supporting area and urban center area. The authors conclude that the interactions between two cities include raw material flow, transportation, tourism, water flow, labor transfer, goods flow, mineral flow, etc. Then new indices are proposed. The Total City Interaction (TCI), that aims to represent the condition of total intensity of the real city interaction. The Environmental Load Index (ELI), that represents the environmental load exerted by city interaction. The Emergy Sustainable Index (ESI), that represents the sustainable scenario of the cooperation between the two cities. Since these indices depend on various flows that are not often known between cities, this author understand that this conceptual model is not feasible to be applied to this study.

Zhang et al. (2012) studied a coastal city called Tianjin in China through emergy synthesis from 1995 to 2009. An ecological risk index system was developed corresponding to the factors of urban ecosystem risk including in Pressure-State-Response model (PSR). It is explained that the PSR provides a mechanism to monitor the status of the environmental and economic. It also provides a framework for investigation and analysis of processes involved in urban ecological risk. The results obtained by the authors have shown that, during the period of the study the pressure rating of the urban ecology risk in this area raised continually. The authors underline that these results comply with relevant laws of correlativity between urbanization and ecological protection in this research area.

Morandi, 2012 developed and applied a new method for understanding and calculating emergy, that is a thermodynamics based function suitable to study sustainability of processes and territorial systems. The author points out that a more coherent emergy methodology is proposed that uses language of indigenous set theory. This new model is applied to territorial systems, and it is said to help to solve problems that have been discussed for many years in emergy literature. The model is applied to real case studies considering nested territorial systems with three levels of organization, i.e. European Union, Italy and Tuscany. However, the interactions between the Tuscany and the larger scale (Italy) were not studied. The author considered that there was no intersection between the flows coming from the larger system (Italy) and the next larger system (EU).

Later, an emergy evaluation of the Chinese economy in the year 2009 was performed by Lou and Ulgiati (2013), aiming to compare the findings with the previous published results, standardizing the previous calculation procedures, in order to use consistent UEVs. The authors point out that the real problem with the time series of values for China is their reliance on different sources of data (not in full agreement to each other) and their lack of standardization. A time series of detailed data is presented, from 1978 to 2009. In 1978, the fraction of renewable resources for China was 46% of total emergy use in the same year. This fraction declined steadily down to a low 9% in 2009 due to larger non-renewable uses. The authors conclude that the present economic development of China is due to, and heavily depends on, large use of local and imported non-renewable resources. In the same period, the emergy per capita in China increased four times. It is shown by means of the performance indicators ELR, EYR and ESI that China is moving toward a scenery of small sustainability due to the dependence on non-renewable and imported sources. It is suggested that China should try to rely on local resources to the largest possible extent and, at the same time, should try to minimize its environmental load by decreasing the use of non-renewables and increasing the ESI.

In 2013, Liu et al. presented an integrated ecological economic assessment considering the economic and ecological losses, as well as, a sustainability policy-making framework for 31 typical Chinese cities, in view of spatial variations based on thermodynamic analysis. The objective was to provide a reference towards how the urban environmental impacts drive economic policy and sustainability. The authors emphasize that economic and ecological loss varies significantly across cities both in the total sum due to diversities of geographic features, economic development levels and local energy use availability. The results suggested that emissions substantially reduced the sustainability of the urban socioeconomic system by pulling resources for damage repair and for replacement of lost natural and human-made capital. Finally, it is advised that the investment of the waste treatment investment, which acts as a balanced system for entropy turbulence, should be encouraged.

Yang et al. (2013) have used emergy accounting and carbon footprint accounting methods to investigate the environmental pressure generated by household consumption in Xiamen, a coastal city in southeast China. The two methods are combined to investigate household consumption and resulting environmental footprint, within a proposed urban spatial conceptual framework. The authors distinguish between the resource extraction, consumption and disposal stages within an urban spatial conceptual framework, comprising the Urban Footprint Region (UFR) and Urban Sprawl Region (USR) and analyze five environmental footprint categories associated with cross-boundary household emergy and carbon flows. It is explained that the analysis of household consumption improves understanding of the overall role and responsibility distribution of households, enabling the design of appropriate and effective policies for cooperation in urban sustainability and environmental footprint reduction. Using the inflow-outflow process-based emergy, household emergy inflows, usage and outflows totaled 1.52 x 10^{24} sej/yr in 2009. 87.3% of this value is from construction products and at the waste disposal stage, annual emergy flows were 9.95% of total emergy, including exported waste (solid wastes and waste water) and exported services. Of the five environmental footprint categories considered, transport fuel, building materials and food contribute most to the environmental footprint in both emergy accounting and carbon footprint accounting methods.

The available literature regarding emergy synthesis applied to urban systems reveals a great concern in understanding, quantifying and characterizing the flows that give support to an urban area. Some papers focus this concern toward the application of the information to improve public policies, (Pulselli et al. 2007a; Ascione et al. 2009; Pulselli, 2010; Giannetti et al. 2010), other papers focus in measuring and comparing in order to determine the best arrangement (Lei at al. 2008; Zhang et al. 2009a; Zhang et al. 2012) or the to monitor cities' development along time (Lei and Wang, 2008; Zhang et al. 2009b; Zhang et al. 2011; Zhang et al. 2012; Lou and Ulgiati 2013). Others concern about developing complementary indices to improve information that maybe used to decision making within specific sectors (Lei at al. 2008; Liu et al. 2009; Zhang et al. 2009; Chen et al., 2011; Yang et al. 2013). However, in all works cited, it is possible to distinguish a great concern in knowing and quantifying the flows that drive the cities activities and also those inter-cities flows that are not commonly accounted.

Based on the literature screening, it is possible to affirm that the study of cities and its interactions is a relatively new subject since most of the literature references have not more than 10 years. This means that there is still a vast space for contribution and developments.

3. Objectives

3.1 General objectives

This work applies the emergy synthesis methodology to evaluate the environmental sustainability of the municipalities that form ABC Paulista, through an approach capable to gather economic and environmental aspects.

3.2 Specific objectives

The main goals of the study are:

- To verify the sustainability of the investigated urban systems, by comparing indicators generated from emergy method.
- To compare the municipalities of this study with the aid of the ternary diagram tool.
- To calculate emergy-based indices in order to compare this study other similar studies related to urban systems performed by other researchers.
- To investigate the carrying capacity of the urban systems to verify which fraction of urban system assets, population, and activity would be sustainable only relying on resources locally available.
- To generate a study that may be used as a reference for decisions related to policies for environmental sustainability of ABC Paulista.
- To contribute with the ongoing project in the research line with one more study related to sustainability of urban and regional systems.

4. Methodology

4.1 Emergy Synthesis

The methodology used is based on the concepts of emergy analysis, developed by Odum (1996) that contemplates the resources used to obtain a product, process or service, being them provided by the environment or economy.

According to the methodology, the resources that support any product, service or system can be divided into renewable (R), non-renewable (N), called local resources (I= R+F), and purchased resources (F) that come from outside the system. The total emergy (U) is the sum of renewable (R), non-renewable (N), and purchased resources (F).

Odum (1996) proposed this methodology based on the accounting of solar emergy, to represent all flows in a common unit. Emergy, spelled with an 'm', measures both the work of nature and that of humans in generating products and services. Emergy is defined as the sum of all inputs of energy needed directly or indirectly to make any product or service.

Odum (1996) defined the concept of transformity, which is the quotient between the emergy of a product and its energy. The transformity unit is the solar emergy necessary to obtain one joule of a product or service. Its unit is the emjoule, solar emergy joule per joule (sej/J). In some cases, it is convenient using emergy per unit, such as mass, to transform the accounted quantities in emergy. The Unit Emergy Value (UEV) also represents the transformity, but this term also may represent the emergy regarding relative to quantities given in other units, such as mass and currency. The use of a common basis (solar equivalent joules, sej) permits to account all the energy contributions to obtain a certain product or service.

By means of the emergy diagrams, (Odum,1996) it is possible to represent the system's energy flows. These flows are related to flows of natural renewable resources (R), natural non-renewable resources (N) or purchased resources (F), those from the economy or not local non-renewable resources (Fig. 2).

The purpose of the system diagram is to conduct a critical inventory of processes, storages and flows that are relevant to the system under consideration and are, therefore, necessary to be evaluated. Components and flows within diagrams are arranged from left to right reflecting more available energy flow on the left, decreasing to the right with each successive energy transformation.

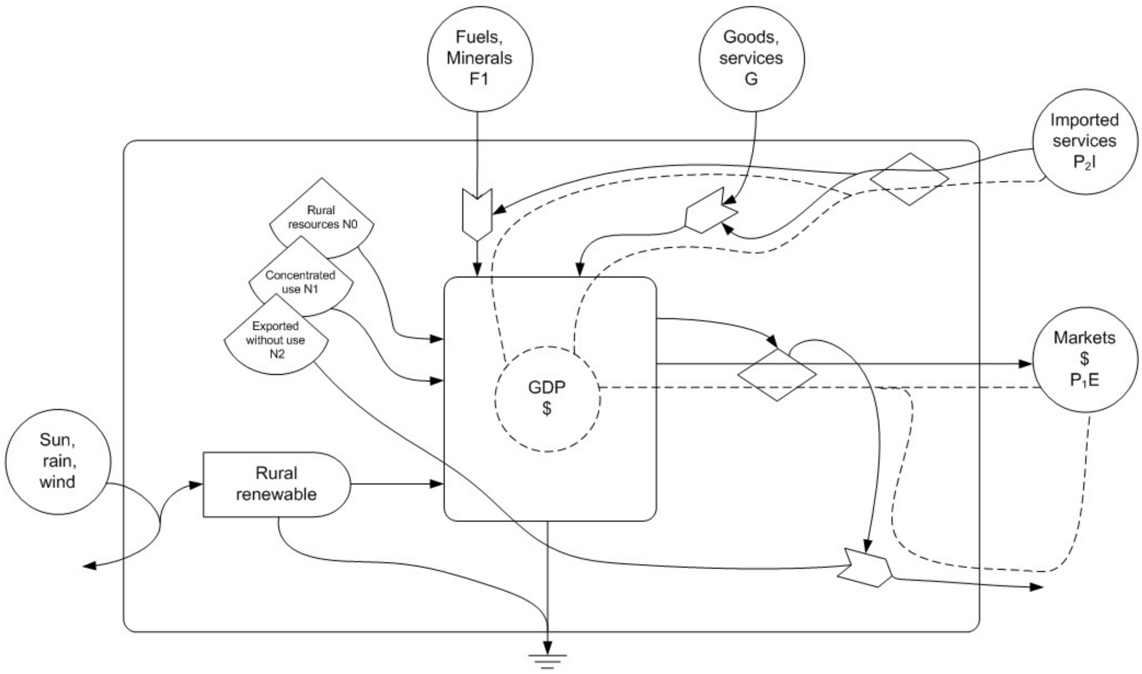

Fig. 2 – Emergy Flow Diagram for Regional Systems (adapted from NEAD - National Environmental Accounting Database).

The construction of the diagram is performed with the use of specific symbols (Table A1, Appendix A) that standardize its construction that were defined by Odum (1996).

It was used the model proposed by Sweeney et al. (2007) for the evaluation of countries. The indices proposed in this model were used (described in section 4.2), as well as the shift-share analysis, that was used to estimate the flows from the internal economy (Brazil), described in section 4.3.

4.2 Emergy indices

4.2.1 Emergy indices for general use

The environmental loading ratio, ELR, is an indicator of the stress of the local environment due to the production activity. It is the ratio of the economic inputs (F) and local non-renewable emergy (N) to free environmental emergy

(R) (Eq. 1). The lower the portion of renewable emergy used, the higher the pressure on the environment

$$ELR=\frac{F+N}{R} \quad (1)$$

The emergy yield ratio, EYR, is the ratio of the emergy of the output to the emergy of economics inputs, F and represents the emergy return on economic investment (Eq. 2). This indicator computes the process ability to profit from local resources. The lower the portion of the economic input (F) the higher is this ability. However, this index does not differentiate local and imported resources.

$$EYR=\frac{U}{F}=\frac{R+N+F}{F} \quad (2)$$

The emergy investment ratio, EIR, shows the relation between the emergy of the economic inputs with those provided by the environment, renewable or not (Eq. 3). It evaluates if a system is an efficient user of emergy investments.

$$EIR=\frac{F}{N+R} \quad (3)$$

The emergy sustainability index, ESI, arises from the ratio of EYR to ELR, which is a sustainability function for a given process or economy. The fact that it is preferable to have a higher emergy yield per unit of environmental loading defines this index, that evidences if a process offers a profitable contribution to the user with a low environmental pressure (Eq. 4).

$$ESI=\frac{EYR}{ELR}=\frac{U/F}{(N+F)/R} \quad (4)$$

The emergy money ratio, EMR, is calculated by the sum of all emergy of the system (U) divided by the GDP of the region that is being studied (Eq. 5). This indicator makes possible to evaluate and quantify each emergy flow in monetary units. The EMR is a relative measure of purchasing power when the ratios associated with two or more nations or regions are compared.

$$EMR=\frac{U}{GDP} \quad (5)$$

4.2.2 Emergy indices developed to evaluate nations/regions/urban systems

The emergy flows, shown in Fig. 2 permit to calculate different indices that can help to examine and monitor a system. The renewable emergy flow (R) corresponds to the sum of all renewable emergy that flows into the system except those that are not accounted to avoid double accounting.

The flow from indigenous non-renewable reserves (N) corresponds to the sum of N_0 and N_1 which are the local non-renewable resources of the system.

The flow of imported emergy is the sum of all purchased resources from outside the system's boundaries (F), goods and electricity (G) and services (P_2I).

Total emergy inflows correspond to the sum of all emergy inflows to the system: renewable (R), non-renewable (N) and imported emergy (F+G+ P_2I). In this study, the total emergy used (U) has the same value of the total emergy inflows since these municipalities have no exports without use (N_2).

The total exported emergy regards the emergy of exported goods and services (P_1E).

The percentage of emergy of indigenous sources is calculated according to equation 6.

$$\text{Fraction emergy use derived from indigenous sources}=\frac{(N_0+N_1+R)}{U} \quad (6)$$

Imports minus exports are calculated by means of equation 7.

$$\text{Imports minus exports}=(F+G+P_2I)-(P_1E) \quad (7)$$

Exports to Imports are calculated using equation 8.

$$\text{Exports to Imports}=\frac{(P_1E)}{(F+G+P_2I)} \quad (8)$$

Local renewable fraction calculates the percentage of renewable resources compared to the total emergy (Eq. 9).

$$\text{Local renewable fraction}=\frac{R}{U} \quad (9)$$

Purchased fraction calculates the percentage of purchased resources compared to the total emergy (Eq. 10).

$$\text{Purchased fraction}=\frac{(F+G+P_2I)}{U} \quad (10)$$

Imported service fraction calculates the percentage of imported service compared to the total emergy (Eq. 11).

$$\text{Imported service fraction} = \frac{P_2 I}{U} \quad (11)$$

Fraction of use that is “free” calculates the percentage of emergy that is “free”, which involves sources provided by nature, compared to the total emergy (Eq. 12).

$$\text{Fraction of use that is “free”} = \frac{(R+N_0)}{U} \quad (12)$$

The ratio of concentrated to rural use confronts the use of imported energy, materials, goods and services with the renewable and rural sources. (Eq. 13).

$$\text{Ratio of concentrated to rural} = \frac{(F+G+P_2I+N_1)}{(R+N_0)} \quad (13)$$

Empower density represents the ratio of total emergy use in the economy of a region or nation to the total area of the region or nation (Eq. 14).

$$\text{Empower density} = \frac{U}{\text{area}} \quad (14)$$

Emergy per capita represents the ratio of total emergy use in the economy of a region or nation to the total population. Emergy per capita can be used as a measure of potential, average standard of living of the population (Eq. 15).

$$\text{Emergy per capita} = \frac{U}{\text{population}} \quad (15)$$

Renewable carrying capacity at present living standard is calculated using equation 16. It represents the environment’s ability to support economic development based solely on its renewable emergy sources. The result is the population capable to “sequester” the equivalent emergy that comes only from renewable sources (Brown and Ulgiati, 2001).

$$\text{Renewable carrying capacity at present living standard} = \frac{R}{U} \times \text{population} \quad (16)$$

Developed carrying capacity at developed living standard is calculated using equation 17. The result is the population capable to “sequester” the equivalent emergy that comes only from renewable sources if the quantity of these resources was multiplied by eight. The use of this value (eight) assumes that developed countries use eight times more emergy than their renewable base supply.

$$\text{Developed carrying capacity at present living standard} = 8 \times \frac{R}{U} \times \text{population} \quad (17)$$

Electricity fraction calculates the percentage of emergy of electricity compared to the total emergy (Eq. 18).

$$\text{Electricity fraction} = \frac{\text{Emergy of electricity}}{U} \quad (18)$$

Fuel use per capita is calculated using equation 19.

$$\text{Fuel use per person} = \frac{\text{Emergy of fuels}}{\text{population}} \quad (19)$$

4.3 Shift-Share analysis

In the study of countries, states, counties, cities, frequently some data, being them economic, environmental or social, become more and more scarce the smaller the system is. Due to the lack of regional data regarding each municipality of ABC Paulista, a tool has been considered as a way to quantify the exchanges between ABC Paulista and Brazil.

The Shift-Share analysis uses the concept of observing the quantity of labor that is used in a certain sector or industry and compare it to a larger scale scenario where the studied place is inserted. For example, a municipality or a group of municipalities and the country where they are placed. In this way the Shift-Share analysis was applied to Santo André, São Bernardo do Campo and São Caetano do Sul, which are placed in the larger scenario, Brazil (Fig. 3). It was also applied between ABC as a whole and Brazil (Fig. 4). Detailed calculations for the Shift-share analysis applied to ABC and its municipalities can be found in Appendix D.

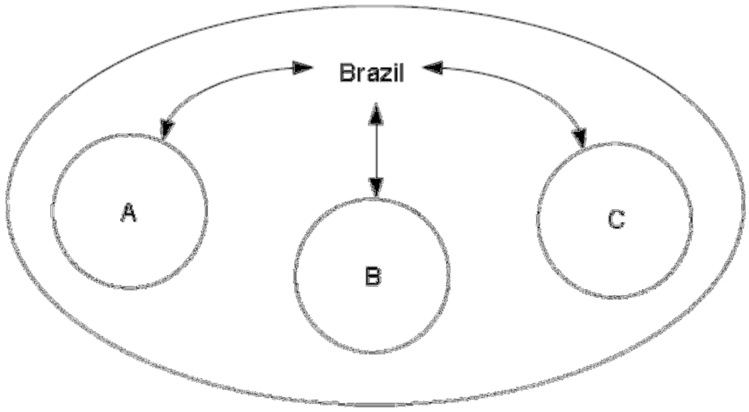

Fig. 3 – Shift share analysis between Santo André, São Bernardo do Campo and São Caetano do Sul and the rest of Brazil.

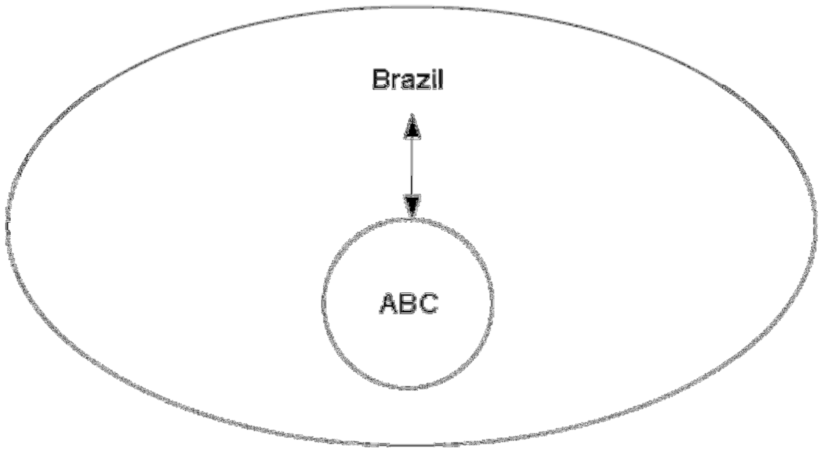

Fig. 4 – Shift share analysis between ABC as a whole and the rest of Brazil.

Three categories of industries were chosen as representative of the major activities of exchanges between the municipalities and Brazil. They are: Industry (including construction), Services (including commerce) and Agriculture and livestock.

Data regarding local and national employment was gathered from Instituto Brasileiro de Geografia Estatística (IBGE), in the census of 2010 published in 2013.

The first step to apply the Shift-share analysis is the calculation of the location quotients (LQ) of a given industry. The “location quotient” is a statistical device that measures, usually in terms of employment, the degree to which a given industry is concentrated in a given place. Quite apart from its role in estimating the level of exports, it is an extremely useful descriptive measure in urban studies. It is defined as the percentage of local employment accounted for by a given industry divided by the percentage of national employment in that industry (Heilbrun, 1981).

Heilbrun, 1981, points out that three assumptions have to be made in order to use the location quotients: (1) patterns of consumption do not vary geographically; (2) labor productivity does not vary geographically; (3) each industry produces a single, perfectly homogeneous good.

The location quotients are calculated as follows, (Eq. 20):

$$LQ_i = \frac{\frac{e_i}{e}}{\frac{E_i}{E}} \qquad (20)$$

Where:

e_i = local employment in the i^{th} industry

e = total local employment

E_i = national employment in the i^{th} industry

E = total national employment

After the calculation of the location quotients, it is possible to evaluate if the municipality in study, imports or exports materials related to that given industry. If the value of LQ is higher than 1.0, the municipality has a higher employment associated to the given industry compared to the national scenario. In this way, it is understood that the municipality is exporting products related this industry. If the value of LQ is below 1.0, the meaning is that the municipality has a smaller employment in this given industry compared to the national scenario. In this way, it is importing products related to this industrial sector.

After LQ calculations, it is necessary to quantify the amount of exports and imports. Considering that each employee of an industry generates a certain amount of money, it is possible to quantify how much money is exported or imported in terms of labor using equation 21:

$$X_i = \left(\frac{e_i}{e} - \frac{E_i}{E} \right) \times e \qquad (21)$$

Where:

X_i = export or import employment in the i[th] industry

$\frac{e_i}{e}$ = the actual percentage of employment devoted to such production

$\frac{E_i}{E}$ = the percentage of local employment that would have to be devoted to the production of the i[th] good to supply local demand

If the value of X_i is negative the amount of money of that given industry is imported due to the fact that products related to that are not produced locally, but imported from the larger scale scenario where the system is inserted. If the value of X_i is positive it means that the amount of money of that given economic activity is exported due to the fact that products related to that, are produced in a larger amount than the local need or use.

Using data related to economy (X_i) and employment (LQ) is possible to calculate how much money each employee generates in that given industry or sector. This calculation is made dividing the GDP of the given industry or sector by the number of employees of the industry or sector in study, as shown in equation 22.

$$\text{Value per employee} = \frac{GDP_{SECTOR}}{\text{number of employees of the sector}} \qquad (22)$$

With this value per employee, it is now possible to quantify monetarily the amount of money imported or exported between the municipality or group of municipalities and Brazil, using equation 23. The value per employee of the sector used will be the value for Brazil if the municipality is importing goods related to that sector. If the municipality is exporting goods related to that sector, the value used is the one calculated for each municipality.

$$\text{Value exported or imported} = X_i \times \text{value per employee of the sector} \qquad (23)$$

With the monetary value of the export or import, it is calculated now the emergy related to the exports or imports can be estimated, using equation 24.

$$\text{Emergy} = \text{value exported or imported} \times \text{EMR of the municipality or Brazil} \qquad (24)$$

4.4 Emergetic ternary diagram

The emergetic ternary diagram (Fig. 5) was developed by Giannetti et al. (2006) and is presented as a graphic tool to assist environmental accounting and environmental decision-making based on emergy analysis. The graphical representation of the emergy accounting data makes it possible to compare processes and systems with and without ecosystem services, to evaluate improvements and to follow the system performance over time. The graphic tool is versatile and adaptable to represent products, processes, systems, countries, and different periods of time.

The graphic tool permits to draw three lines shown in Fig. 5 indicating constant values of the sustainability index. These lines are presented independently and the value of ESI may be fixed by the user. The sustainability lines depart from the N apex in the direction of the RF side allowing the division of the triangle in sustainability areas, which are very useful to identify and compare the sustainability of products and processes. When ESI < 1, point C, products and processes are not sustainable in a long term. Systems presenting 1 < ESI < 5, point B, may have a sustainable contribution to the economy for medium periods and processes with ESI > 5 can be considered sustainable in a long term, point A (Giannetti et al., 2006).

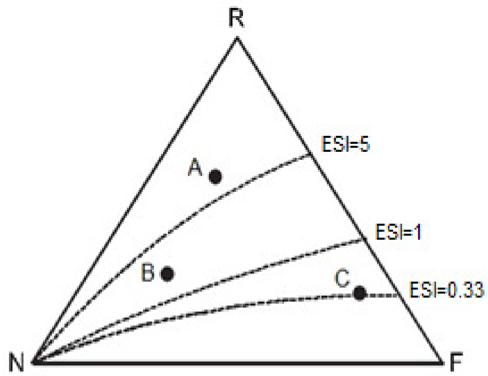

Fig. 5 – Emergetic ternary diagram showing the sustainability lines (adapted from Giannetti et al. (2006)).

4.5 Emergy indices of carrying capacity

The carrying capacity indices are expressed as land area required to support an economic activity (Brown and Ulgiati, 2001). The indirect area defined as the "renewable support area" ($SA_{(r)}$) was calculated according to equation 25. Renewable support area is derived by dividing the total emergy input to a process (F+N) by the average renewable empower density of the region ($Empd_{(r)}$) in which it is located.

$$SA_{(r)} = \frac{F+N}{Empd_{(r)}} \qquad (25)$$

The $SA_{(r)}$ is the necessary area of the surrounding region that would be required if the system's activities were solely using renewable emergy inputs. This value establishes a lower limit to environmental carrying capacity because it requires the largest support area, thereby placing the limits on development.

The ELR reflects the potential environmental strain or stress of a development when compared to the same ratio for the region and can also be used to calculate carrying capacity. Urban settlements have ELR's that are higher than the regional average, due to the large convergence of non-renewable and outside resources into a relatively small area. The support area required to balance the system of interest with the ELR of the region was estimated according to equation 26:

$$SA_{(ELR)} = \frac{R^{*}}{Empd_{(r)}} \qquad (26)$$

Where R* = (F + N)/$ELR_{(r)}$; and $ELR_{(r)}$ is emergy loading ratio of the region. The regional boundary affects the analysis, and in this case, the political region of the state of São Paulo was chosen to determine the area of support necessary to remain competitive with the surrounding conditions. Values of $Empd_{(r\ SP\ state)} = 4.40 \times 10^{11}$ sej/m^{2}yr and the $ELR_{(r)} = 6.68$ for São Paulo state were taken from (Demétrio, 2011).

The estimate areas (using emergy) when compared with the available areas is a way to calculate the deficit (appropriation > carrying capacity) or the surplus (appropriation < carrying capacity). In case of deficit, the condition of overshoot is reached which indicates unsustainability or dependence on external resources.

The land area required to support the municipalities was also compared to an area of Atlantic forest, which represents the original natural environment of the region. The carrying capacity calculation using the Emergy Net Primary Productivity (Agostinho and Ortega, 2010; Siche et al., 2010) converts the non-renewable emergy used by the municipalities system in its equivalent Atlantic forest area (Eq. 27) and the result is a quantitative measure on the natural area that corresponds to the emergy used by the cities showing the amount of hectares of tropical forest needed to balance the emergy used by the municipal activities.

$$SA_{(r\ atltantic\ forest)} = \frac{F+N}{Empd_{(atltantic\ forest)}} \qquad (27)$$

Where $SA_{(r\ atlantic\ forest)}$ is the support area using emergy and NPP; $Empd_{(atlantic\ forest)}$ is the empower density of Atlantic forest (calculation in Appendix G).

4.6 Data collection

The emergy accounting was performed based on the tables from National Environmental Accounting Database (NEAD, 2000); as described by Sweeney et al. (2007). The energy of renewable resources and the flow of imported and exported resources were obtained from governmental institutions websites and from the city council. (IBGE, 2011, 2012, 2013; CRESESB, 2010; SECEX, 2011; SEADE, 2011, City council web sites of each municipality.) The UEVs (Table 2) were based on information obtained by bibliographic research performed in scientific periodicals, thesis, dissertations and books.

The values of UEVs are based on the approximate planetary baseline of 15.83 x 10^{24} sej/year (Odum et al., 2000). Since some of the UEVs found in the literature do not show clearly if the labor and services are or not included in the calculations, a sensibility analysis was performed (Appendix F). For the three most representative items (in terms of emergy contribution) other UEVs, found in other literature, were tested in order to observe the change in the total emergy. No variation above 6% was observed and the UEVs shown in Table 2 were considered reliable.

Table 2 – References of unit emergy values (UEV) used in this work.

Item	Unit	UEV (sej/unit)	Ref.
Solar radiation	J	1	Odum, 1996
Kinetic wind energy	J	2.45×10^{3}	Odum et al., 2000
Rain (Chem. energy in green areas)	J	3.10×10^{4}	Odum et al., 2000
Rain (Chemical energy of run-off)	J	3.10×10^{4}	Odum et al., 2000
Rain (Geopotential energy)	J	4.70×10^{4}	Odum et al., 2000
Geothermal heat	J	5.80×10^{4}	Odum et al., 2000
Natural gas	J	6.84×10^{4}	Bastianoni et al., 2005
Sugarcane Ethanol	J	8.18×10^{4}	Pereira and Ortega, 2010
Topsoil loss	J	1.24×10^{5}	Odum, 2000
Food	J	1.43×10^{5}	Brown and McClanahan, 1996
Diesel oil	J	1.11×10^{5}	Odum, 1996
Gasoline	J	1.11×10^{5}	Odum, 1996
Electricity	J	2.77×10^{5}	Odum, 1996
Treated water	L	1.55×10^{9}	Buenfil, 2001
Evaporation from dam	m^3	2.44×10^{11}	Buenfil, 2001
Water dam	m^3	3.81×10^{11}	Buenfil, 2001
Rocks	kg	1.64×10^{9}	Odum et al., 2000
Cereals and derivatives	kg	6.04×10^{11}	Odum, 1996
Coffee	kg	6.10×10^{11}	Cuadra and Rydberg, 2006
Chemicals	kg	6.38×10^{11}	Brown et al., 1992
Wood	kg	6.79×10^{11}	Odum, 1996
Aluminum	kg	7.76×10^{11}	Bargigli and Ulgiati, 2003
Fruits and vegetables	kg	1.01×10^{12}	Odum, 1996
Wine and alcoholics	kg	1.41×10^{12}	Odum, 1996
Other Metals	kg	1.54×10^{12}	Buranakarn, 1998
Cement	kg	2.20×10^{12}	Buranakarn, 1998
Sugar	kg	2.98×10^{12}	Odum et al., 1993
Steel and Iron	kg	3.16×10^{12}	Bargigli and Ulgiati, 2003
Cooper	kg	3.36×10^{12}	Brown and Ulgiati, 2004
Glass	kg	3.50×10^{12}	Brown and Ulgiati, 2004
Paper and derivatives	kg	6.55×10^{12}	Odum, 1996
Plastic	kg	9.68×10^{12}	Brown and Arding, 1991
Machinery	kg	1.12×10^{13}	Brown and Bardi, 2001
Milk, cheese and other derivatives	kg	1.44×10^{13}	Odum, 1996
Cotton	kg	2.10×10^{13}	Brandt-Williams, 2001
Meat	kg	3.00×10^{13}	Odum, 1996
Textiles	kg	1.34×10^{14}	Odum, 1996
Fish	kg	2.78×10^{14}	Odum, 1996
Olive and seeds oils	kg	4.25×10^{14}	Odum, 1996
Gold	kg	1.50×10^{16}	Ingwersen, 2011
EMR of the state of Brazil	USD	4.78×10^{12}	Demétrio, 2011
Labor (worker from SP state)	people	2.04×10^{16}	Demétrio, 2011

For the topsoil loss, it was considered the alternative of calculating it using the entire area of the municipalities. For this item, it was performed a second calculation, and a comparison was made between the calculation using only the crop area and using the entire area (Appendix F).

5. Results and discussion

This study admits municipality as a territory, with a local government authority and delimited political boundaries, that is composed by rural and urban areas. The emergy synthesis is applied to the group of three municipalities named ABC Paulista, which is composed of Santo **A**ndré (SA), São **B**ernardo do Campo (SBC) and São **C**aetano do Sul (SCS).

Such a complex evaluation task requires system's components and input-output flows to be clearly identified, described and, when possible, quantified. Furthermore, the relations among components, as well as with the surrounding environment also need to be carefully investigated. The emergy flows diagram of ABC Paulista is presented in Fig. 6. The diagram fully describes and helps to understand the dynamics of the urban ecosystem showing the renewable natural resources (rain, wind and sun) that feed the ABC Paulista (urban areas, agricultural areas, industrial activities), and storages (water reservoirs, standing tree biomass, built environment). The diagram also shows physical components and economic sectors, as well as, their interactions through pathways of matter and energy flows exchanged, providing a preliminary picture of internal complexity and dynamics.

The Billings dam is partially located at SA and SBC supplying water to various municipalities in the region of Greater São Paulo. The water consumed from this storage was considered a renewable resource (R). SCS does not hold a water reservoir inside its boundaries.

The municipalities purchase resources from outside their borders and these resources (F) are shown in the upper part of the diagram (water, fuel, electricity, machinery, products and services). On the right side of the diagram are illustrated the financial transactions among municipalities and foreign markets. Within the outer limit of ABC's diagram, the infrastructure of urban activities represented by built and natural systems is shown.

There are also activities that are undertaken within ABC area in order to supply the needs of the municipality regarding water treatment and waste disposal. Industrial and manufacturing activities use the built environment and all items that cross the system's boundary, yielding products and services that are exported to other locations outside the system. All these activities generate a stock of capital that is represented within the studied system.

In spite of the diagram be integrated for the three municipalities and the municipalities be neighbors, there are differences among them that may be highlighted. The first difference regards to the industry activity profile. SA holds an industrial activity that is more focused in the chemical sector while SBC and SCS have their industrial activities more focused in the automotive industry. Another difference is the composition of the municipality structure. Both, SA and SBC hold urban and rural areas. Differently, SCS was surrounded and limited over time by the urban growth of the capital (São Paulo) and other highly urbanized centers. SCS does not have rural areas and currently has no place for expansion other than vertical growth. Its green area is due to reforestation projects and accounts for 0.14% of the total area.

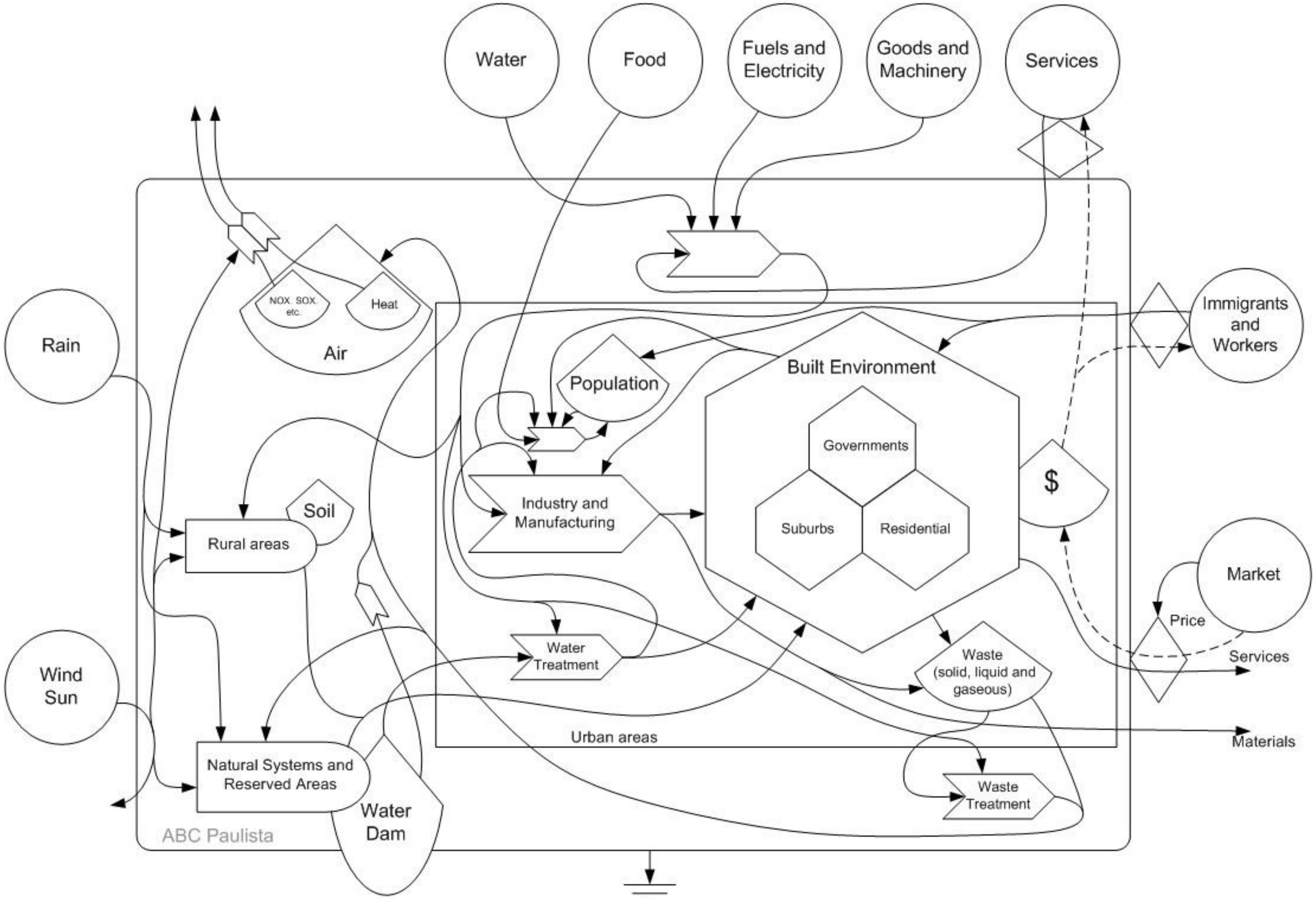

Fig. 6 – System's diagram for ABC Paulista.

Table 3 shows the total emergy for the ABC Paulista (detailed information in Appendix B), Table 4 shows the exports and Table 5 contrasts the emergy flows of the three municipalities. The emergy tables related to each one of the municipalities can be found in Appendix B.

Table 3 makes it clear that ABC is not self-sufficient and depends on resources that come from Brazil and other countries. Imports were divided into those which come from inside and outside Brazil. Calculations for fuels, electricity, treated water and food can be found in Appendix C. Services that come from inside Brazil were calculated using the Shift Share analysis (Appendix D). In regard to imports from outside Brazil, data from SECEX (2011) were used (Appendix C). Direct labor that comes from other municipalities of the state of São Paulo was calculated combining data of Census 2010 published by IBGE (2013).

It is interesting to note that imports from foreign countries contribute in a similar share to the total emergy of ABC (48.6% sej/sej) of those imported from Brazil (51.2% sej/sej), and this may be due to the high use of imported resources by the industrial sector of the municipalities. It is also remarkable that 37.5% of the total emergy of ABC is associated to the services embedded in the imported goods.

Table 4 shows the flows exported to other regions of Brazil and for other countries. Exports were also divided into those which are sold in Brazil and those that are sold directly to other countries. Calculations services of exports can be found in Appendix B. The main products exported by ABC are related to the chemicals industry (plastic and textiles) and the products of automotive sector (machinery and metals, with 321 x 10^{19} sej/year).

Table 3 – Matter, energy and emergy flows supporting ABC.

	Item	Units	Quantity	UEV (sej/unit)	Emergy x 10^{19} (sej/year)	Percentage of the total emergy
Local renewable resources						
1	Solar radiation	J/yr	2.63×10^{18}	1	0.26	<0.1%
2	Rain (Chem. energy in green areas) (*)	J/yr	3.10×10^{15}	3.10×10^{04}	9.63	0.2%
3	Rain (Chem. energy of run-off) (*)	J/yr	1.06×10^{13}	3.10×10^{04}	0.03	<0.1%
4	Rain (Geopotential energy) (*)	J/yr	4.35×10^{14}	4.70×10^{04}	2.04	<0.1%
5	Kinetic wind energy	J/yr	1.14×10^{15}	2.45×10^{03}	0.28	<0.1%
6	Geothermal heat	J/yr	1.01×10^{15}	5.80×10^{04}	5.89	0.1%
7	Water use from Billings dam	m^3/yr	9.66×10^{07}	3.81×10^{11}	3.69	0.1%
8	Evaporation	m^3/yr	1.45×10^{07}	2.44×10^{11}	0.35	<0.1%
	Total of renewable resources (**)				**11.67**	**0.3%**
Local non-renewable resources						
	Topsoil loss	J/yr	6.62×10^{07}	1.24×10^{05}	0.00	<0.1%
	Total of non-renewable resources				**0.00**	**<0.1%**
Imports from inside Brazil						
10	Fuels (Total)	J/yr	--	--	349.84	8.5%
11	Electricity (Total)	J/yr	2.18×10^{16}	2.77×10^{05}	603.35	14.7%
12	Treated water	L/yr	9.81×10^{10}	1.55×10^{09}	15.21	0.4%
13	Food	J/yr	7.50×10^{15}	1.43×10^{05}	107.11	2.6%
14	Services from inside Brazil	USD/yr	2.79×10^{08}	4.78×10^{12}	133.15	3.2%
15	Agriculture goods from inside Brazil	USD/yr	6.94×10^{08}	4.78×10^{12}	331.30	8.1%
16	Labor	people/yr	2.77×10^{05}	2.04×10^{16}	564.56	13.7%
	Total of Imports from inside Brazil (F_{int}) with services				**2,104.51**	**51.2%**
	Total of Imports from inside Brazil (F_{int}) without services				**1,971.37**	
Imports from outside Brazil						
17	Main food items (Total)	kg/yr	--	--	92.09	2.2%
18	Metals (Total)	kg/yr	--	--	51.66	1.3%
19	Chemicals	kg/yr	2.43×10^{08}	6.38×10^{11}	15.54	0.4%
20	Cement	kg/yr	1.26×10^{06}	2.20×10^{12}	0.28	<0.1%
21	Rocks	kg/yr	2.40×10^{06}	1.64×10^{09}	0.00	<0.1%
22	Paper and derivatives	kg/yr	1.84×10^{07}	6.55×10^{12}	12.07	0.3%
23	Plastic	kg/yr	8.73×10^{07}	9.68×10^{12}	84.46	2.1%
24	Textiles	kg/yr	4.66×10^{06}	1.34×10^{14}	62.46	1.5%
25	Glass	kg/yr	3.49×10^{06}	3.50×10^{12}	1.22	<0.1%
26	Machinery	kg/yr	1.20×10^{08}	1.12×10^{13}	133.95	3.3%
27	Wood	kg/yr	9.10×10^{05}	6.79×10^{11}	0.06	<0.1%
28	Cotton	kg/yr	1.68×10^{05}	2.10×10^{13}	0.35	<0.1%
29	Services of imports from outside Brazil	USD/yr	2.84×10^{09}	Diverse	1,542.85	37.5%
	Total of imports from outside Brazil (F_{ext}) with services				**1,997.00**	**48.6%**
	Total of imports from outside Brazil (F_{ext}) without services				**454.15**	
	Total of imports (internal+external) with services				**4,101.51**	**99.7%**
	Total of imports (internal+external) without services				**2,425.51**	
	Total emergy with services				**4,113.18**	
	Total emergy without services				**2,437.18**	

(*) Rain was calculated as the sum of items 2 and the greatest value between items 3 or 4.
(**) The total of renewable resources was calculated comparing the emergy value accounted for rain (explained above) with the sum of items 1 and 6. The greatest value between these two values was considered the total of renewable resources.
Complete tables and detailed calculations are available in Appendices B and C.

Table 4 – Exports of ABC Paulista.

	Item	Units	Quantity	UEV (sej/unit)	Emergy x 10^{19} (sej/year)
Exports to outside Brazil					
30	Main food items (Total)	kg/yr	--	--	7.64
30a	Cereals and derivatives	kg/yr	3.69×10^{07}	6.04×10^{11}	2.23
30b	Fish	kg/yr	4.87×10^{02}	2.78×10^{14}	0.01
30c	Meat	kg/yr	4.86×10^{05}	3.00×10^{13}	1.46
30d	Milk, cheese and other derivatives	kg/yr	2.65×10^{06}	1.44×10^{13}	3.81
30e	Fruits and vegetables	kg/yr	1.19×10^{05}	1.01×10^{12}	0.01
30f	Wine and alcoholics	kg/yr	2.66×10^{05}	1.41×10^{12}	0.04
30g	Coffee	kg/yr	1.01×10^{04}	6.10×10^{11}	0.00
30h	Sugar	kg/yr	2.58×10^{05}	2.98×10^{12}	0.08
31	Metals (Total)	kg/yr	--	--	15.22
31a	Aluminum	kg/yr	3.80×10^{06}	7.76×10^{11}	0.30
31b	Cooper	kg/yr	1.21×10^{07}	3.36×10^{12}	4.07
31c	Steel and Iron	kg/yr	7.25×10^{06}	3.16×10^{12}	2.29
31d	Gold	kg/yr	3.23×10^{03}	1.50×10^{16}	4.85
31e	Other Metals	kg/yr	2.41×10^{07}	1.54×10^{12}	3.71
32	Chemicals	kg/yr	1.72×10^{08}	6.38×10^{11}	10.96
33	Cement	kg/yr	2.61×10^{06}	2.20×10^{12}	0.57
34	Rocks	kg/yr	3.36×10^{05}	1.64×10^{09}	0.00
35	Paper and derivatives	kg/yr	1.00×10^{06}	6.55×10^{12}	0.66
36	Plastic	kg/yr	2.00×10^{08}	9.68×10^{12}	193.18
37	Textiles	kg/yr	1.19×10^{07}	1.34×10^{14}	159.28
38	Glass	kg/yr	8.25×10^{06}	3.50×10^{12}	2.89
39	Machinery	kg/yr	2.73×10^{08}	1.12×10^{13}	306.06
40	Wood	kg/yr	1.23×10^{07}	6.79×10^{11}	0.83
41	Cotton	kg/yr	3.28×10^{02}	2.10×10^{13}	0.00
42	Services of exports to outside Brazil	USD/yr	3.97×10^{09}	1.56×10^{12}	620.95
	Total of exports to outside Brazil				**1,318.23**
Exports to inside Brazil					
43	Exports of industry to inside of Brazil	USD/yr	4.87×10^{09}	1.56×10^{12}	761.80
44	Exports of services to inside of Brazil	USD/yr	0.00×10^{00}	1.56×10^{12}	0.00
45	Labor	people/yr	2.67×10^{05}	2.41×10^{16}	692.30
	Total of exports to inside Brazil				**1,454.10**
	Total of exports				**2,151.38**
	Total Emergy				**4,113.18**

According to the results shown in Table 3 and Table **4**, the ABC imports 4,113 x 10^{19} sej/year to maintain its structure (population and industrial sector activities) and exports 2,151 x 10^{19} sej/year in goods and services. A great share of the emergy accounted to support the ABC is associated to the imported goods from outside Brazil and services associated to them. Thus, it can be inferred that this three municipalities together depend on the resources supplied by the state or the country, especially to maintain their industrial activities. When the emergy accounting is performed without services (from inside and outside Brazil), the ABC still presents a deficit of approximately 274 x 10^{19} sej/year, confirming its dependence on the surrounding regions. The ABC economy contributes with 4.8% of the GDP of the state of São Paulo and with almost 3% of the GDP of Brazil. These economies are tightly linked through imports and exports; therefore, the economy of ABC can be considered as a subsystem of the state economy, functioning as a subsidiary economy within the state economy.

Table 5 shows the emergy flows of each municipality of ABC and Table 6 provides an aggregated list of categories of input flows. The tables clearly show that local flows, renewable or not, are negligible compared to imported emergy flows in all three cities. Despite this result could also have been partially obtained without emergy accounting by only comparing local energy available (solar radiation and wind) to the energy actually used (fossil fuels), several kinds of inputs would be disregarded (rain, minerals, ecosystem services, labor). Since, emergy is calculated by also accounting for the time embodied in the generation of resources (work done by nature in the past), so that transformities include processes occurring at larger spatial and time scales. Using emergy instead of actual energy makes evaluation results sensitive to issues of renewability over time, providing a more comprehensive synthesis of driving forces.

ABC as a whole imports 99.7% of its total emergy. The main inputs of imported goods are the flow of electricity (19.0% in SA, 11.6% in SBC and 16.2% in SCS) followed by fuels (11.3% in SA, 6.6% in SBC and 8.8% in SCS).

Services, a money-based measure of indirect labor supplied and related information and know-how, indicate an emergy flow that is not directly linked to technology and raw resources. While technologies such as automotive assembling or chemicals production are similar, especially in times of globalization of markets, the same does not apply to services, which can be largely different depending on a country's resources and economy. Services associated with imports account for about 31% in SA, 48% in SBC and 36% in SCS, and most of which is supported by non-renewable emergy flows (that is, non-renewable flows driving the economies of Brazil and other countries from which services were purchased). It is interesting to note that in regard to services inside Brazil, both SA and SBC depend on imported services, while SCS exports services to the surrounding regions.

Table 5 – Emergy flows of each municipality of ABC.

	Item	Emergy (sej/year) (x 10^{19}) Santo André	São Bernardo do Campo	São Caetano do Sul
Local renewable resources				
1	Solar radiation	0.08	0.18	0.01
2	Rain (Chem. energy in green areas) (*)	2.38	7.25	0.00
3	Rain (Chem. energy of run-off) (*)	0.01	0.02	0.00
4	Rain (Geopotential energy) (*)	0.39	0.74	0.05
5	Kinetic wind energy	0.08	0.19	0.01
6	Geothermal heat	1.73	4.01	0.15
7	Water use from Billings dam	0.31	3.38	0.00
8	Evaporation	0.00	0.30	0.00
	Total of renewable resources (**)	**2.76**	**7.98**	**0.15**
Local non-renewable resources				
9	Topsoil loss	0.00	0.01	0.00
	Total of non-renewable resources	**0.00**	**0.01**	**0.00**
Imports from inside Brazil				
10	Fuels (Total)	164.57	150.96	34.31
11	Electricity (Total)	276.23	264.04	63.08
12	Treated water	6.43	6.98	1.98
13	Food	44.08	53.08	9.95
14	Services from inside Brazil	99.05	43.12	0.00
15	Agriculture goods from inside Brazil	141.06	157.43	32.81
16	Labor	261.95	234.14	68.47
	Total of Imports from inside Brazil	**993.35**	**909.77**	**210.60**
Imports from outside Brazil				
17	Main food items (Total)	1.16	65.30	25.63
18	Metals (Total)	3.64	47.27	0.76
19	Chemicals	12.23	3.19	0.12
20	Cement	0.14	0.11	0.03
21	Rocks	0.00	0.00	0.00
22	Paper and derivatives	4.20	7.83	0.03
23	Plastic	53.19	30.29	0.99
24	Textiles	22.44	39.67	0.35
25	Glass	0.00	1.07	0.15
26	Machinery	6.59	114.71	12.65
27	Wood	0.00	0.05	0.01
28	Cotton	0.00	0.35	0.00
29	Services of imports from outside Brazil	356.22	1,047.72	138.92
	Total of imports from outside Brazil	**459.81**	**1,357.56**	**179.64**
	Total of imports	**1,453.16**	**2,267.33**	**390.24**
Exports to outside Brazil				
30	Main food items (Total)	0.09	3.71	3.84
31	Metals (Total)	0.00	0.00	0.00
32	Chemicals	6.52	4.32	0.12
33	Cement	0.00	0.48	0.09
34	Rocks	0.00	0.00	0.00
35	Paper and derivatives	0.00	0.64	0.01
36	Plastic	151.22	34.64	7.32
37	Textiles	148.13	10.35	0.80
38	Glass	0.00	2.80	0.08
39	Machinery	4.30	246.21	55.55
40	Wood	0.00	0.71	0.13
41	Cotton	0.00	0.00	0.00
42	Services of exports to outside Brazil	125.72	454.96	38.50
	Total of exports to outside Brazil	**444.81**	**763.85**	**107.80**
Exports to inside Brazil				
43	Exports of industry to inside Brazil	323.72	369.18	56.78
44	Exports of services to inside Brazil	0.00	0.00	3.96
45	Labor	287.50	313.87	83.45
	Total of exports from inside Brazil	**611.22**	**683.06**	**144.19**
	Total of exports	**1,056.02**	**1,446.90**	**252.00**
	Total Emergy	**1,455.93**	**2,275.32**	**390.39**

Complete tables and detailed calculations are available in Appendices B and C.

Table 6 shows the summary flows of each municipality. In regard to imported services, it was observed that SA imports the correspondent to 31.3% of its total emergy (Appendix B). SBC is the municipality that imports more services (47.9%, Appendix B) and SA exports the highest quantity of goods (44.2% of its total exports, Appendix B).

Table 6 – Emergy summary flows of each municipality of ABC.

Variable	Item	Santo André		Santo Bernardo do Campo		São Caetano do Sul	
		Emergy sej/yr	Dollars	Emergy sej/yr	Dollars	Emergy sej/yr	Dollars
R	Renewable Emergy Flow	2.76×10^{19}		7.98×10^{19}		1.55×10^{18}	
N	Total Non-renewable Emergy Flow	2.81×10^{16}		1.44×10^{17}		0.00×10^{00}	
F_{total}	Imports	8.35×10^{21}		9.85×10^{21}		1.83×10^{21}	
F	Fuels	1.65×10^{21}		1.51×10^{21}		3.43×10^{20}	
G	Goods and Electricity Imports	6.70×10^{21}		8.35×10^{21}		1.49×10^{21}	
I	Money ($) for Imports		9.56×10^{08}		2.58×10^{09}		2.95×10^{08}
P_2I	Emergy of Imported Services	4.55×10^{21}		1.09×10^{22}		1.39×10^{21}	
E	Money ($) for Exports		2.27×10^{09}		5.24×10^{09}		1.13×10^{09}
P_1E	Emergy of Exported Goods and Services	1.01×10^{22}		1.42×10^{22}		2.37 x 1021	
X	Gross Domestic Product (GDP)		7.35×10^{09}		1.45×10^{10}		4.46×10^{09}
P2	São Paulo State Emergy Money Ratio (EMR)	1.68×10^{12}		1.68×10^{12}		1.68×10^{12}	
P1	Emergy Money Ratio (EMR)	1.98×10^{12}		1.57×10^{12}		8.75×10^{11}	

The evaluation of the indicators calculated for the three municipalities (Table 7) may help to clarify the results and understand the composition of the ABC Paulista.

A systematic analysis of the indices and indicators shown in Table 7 was performed. SCS counts with only 1.3% of the local renewable resources of ABC and may rely on the renewable resources of SA and SBC (line1). The soil used for the crop in rural activities contributes only in SA and SBC (line 2). The flow of imported emergy is more significant in SBC, which contributes with almost 50% to the ABC's emergy of imports (line 3). The contributions to the total ABC's emergy inflow and total emergy used have the same proportions, since all municipalities account for more than 99% of purchased inputs (line 4 and line 11) and have no non-renewable resources exported without use (N_0, line 5).

Table 7 – Emergy indices for of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC Paulista.

Item	Indicator	Expression	ABC	SA	SBC	SCS
1	Renewable emergy flow	R	1.17×10^{20}	2.76×10^{19}	7.98×10^{19}	1.55×10^{18}
2	Flow from indigenous non-renewable reserves	N	8.22×10^{12}	2.81×10^{16}	1.44×10^{17}	0.00×10^{00}
3	Flow of imported emergy	$F+G+P_2I$	4.23×10^{22}	1.29×10^{22}	2.08×10^{22}	3.22×10^{21}
4	Total emergy inflows	$R+N+F+G+P_2I$	4.25×10^{22}	1.29×10^{22}	2.09×10^{22}	3.22×10^{21}
5	Total emergy used, U	$N_0+N_1+R+F+G+P_2I$	4.25×10^{22}	1.29×10^{22}	2.09×10^{22}	3.22×10^{21}
6	Total exported emergy	PE	2.77×10^{22}	1.01×10^{22}	1.42×10^{22}	2.37×10^{21}
7	Fraction emergy use derived from indigenous sources	$(N_0+N_1+R)/U$	0.27%	0.21%	0.38%	0.05%
8	Imports minus exports	$(F+G+P_2I)-(PE)$	1.46×10^{22}	2.83×10^{21}	6.63×10^{21}	8.44×10^{20}
9	Export to Imports	$(PE)/(F+G+P_2I)$	0.65	0.78	0.68	0.74
10	Fraction used, local renewable	R/U	0.00	0.00	0.00	0.00
11	Fraction of use purchased	$(F+G+P_2I)/U$	99.73%	99.79%	99.62%	99.95%
12	Fraction imported service	P_2I/U	53%	35%	52%	43%
13	Fraction of use that is free	$(R+N_0)/U$	0.27%	0.21%	0.38%	0.05%
14	Ratio of concentrated to rural	$(F+G+P_2I+N_1)/(R+N_0)$	362.94	466.48	260.09	2,078.79
15	Use per unit area, Empower Density	U/(area ha)	7.12×10^{13}	7.39×10^{13}	5.14×10^{13}	2.15×10^{14}
16	Use per person	U/population	2.59×10^{16}	1.92×10^{16}	2.58×10^{16}	2.12×10^{16}
		Population	1.64×10^{06}	6.73×10^{05}	8.11×10^{05}	1.52×10^{05}
17	Renewable carrying capacity at present living standard	(R/U) (population)	4.50×10^{03}	1.44×10^{03}	3.10×10^{03}	7.31×10^{01}
18	Developed carrying capacity at same living standard	8(R/U)(population)	3.60×10^{04}	1.15×10^{04}	2.48×10^{04}	5.85×10^{02}
19	Ratio of use to GDP, emergy/dollar ratio	P1=U/GDP	1.62×10^{12}	1.76×10^{12}	1.44×10^{12}	7.22×10^{11}
20	Ratio of electricity to use	(el)/U	14.21%	21.36%	12.64%	19.59%
21	Fuel use per person	fuel/population	2.14×10^{15}	2.44×10^{15}	1.86×10^{15}	2.26×10^{15}
22	Emergy Investment Ratio	$(F + G + P_2I) / (R+N_0+N_1)$	362.94	466.47	260.08	2,078.79
23	Environmental Loading Ratio	$(F+G+ P_2I+N_0+N_1) / R$	362.94	466.95	260.55	2,078.79
24	Emergy Yield Ratio	$U/(N_0+N_1+F+G+P_2I)$	1.003	1.002	1.004	1.000
25	Emergy Sustainability Index	EYR / ELR	0.003	0.002	0.004	0.000

SBC is responsible for about half of the ABC's exported emergy (line 6), but contributes with almost 50% to the total emergy (lines 4 and 5). This results suggest that there must be internal emergy flows (among the three cities) that are contributing to this high outflow. The fraction of emergy use from indigenous sources is less than 0.4%, especially low value is observed for SCS (0.05%), line 7 and line 10. Imports minus exports indicator is positive for all municipalities confirming the increase in quality generated by the internal transformations (line 8). This is a major characteristic of urban systems that concentrate activities that are highly dependent on imports. The ratio exports to imports shows that SA is the leading exporter of the group, followed by SCS and SBC (line 9). SBC is the greatest service importer (52% of emergy for services) followed by SCS, 43% and SA, 35% (line 12). The ratio of concentrated to rural use confronts the use of imported energy, materials, goods and services with the renewable and rural sources. As expected, in all cases there is an intensive use of concentrated energy of about 466:1 for SA, 260:1 for SBC, and 2,079:1 for SCS (line 14). The empower density of the ABC Paulista is the average of the empower of SA and SBC. SCS has an empower density more than four times higher that SBC, but it is compensated by the other two municipalities (line 15). The use of emergy per person is similar for all three municipalities (line 16), and the same similarity was found for the use of fuel per person (line 21). The ratio of electricity use will be discussed in Fig. 12 and Table 9. The emergy to money ratio (EMR) also shows that, despite the lower value of SCS due to its higher GDP, the ABC presents and EMR value similar to those of SBC and SA (line 19). These results show that to each dollar in SCS less emergy is required or 7.22×10^{11} sej. On the other hand, to get a dollar in SA, 1.44×10^{12} sej will be required. According to Odum (1996), SCS has an advantage in trading with SBC and SA.

The renewable carrying capacity at present living standard calculated for municipalities brings interesting results (line 17). The environment's ability to support economic development based solely on its renewable emergy sources would carry only 4,500 persons in the ABC region. The value contrasts with the real population of more than 1,600,000 persons. The area of SCS would support only 0.0005% of its population on a renewable basis. The ABC's population capable to get the equivalent emergy that comes only from renewable sources at developed living standard would use eight times more emergy (Odum, 1996). The region would be capable to hold about 36,000 persons (line 18).

For countries, the developed carrying capacity is calculated considering F/(R+N) = 8, but at urban scale results are substantially higher. The accounting performed for Rome (Ascione et al., 2009) reveals the F/(R+N) value approximately 50. For the present living standard the ABC Paulista would have to count with 363 times (F/(R+N)) the actual renewable resources it has. For the three municipalities, the values would be about 466 for SA, 260 for SBC and 2,079 for SCS.

Since this urban system counts with more than 1,600,000 inhabitants, it is reasonable to affirm that the living standard of this concentrated urban structure is maintained at the expense of well-being taken from people living in other regions.

5.1. The analysis of ABC's indicators using the ternary diagram

The emergy indices are discussed with the aid of the emergy ternary diagram (Fig. 7 and Fig. 8).

The relation between the purchased resources with the local resources, renewable or not (EIR), for ABC Paulista is about 363 (Table 7, line 22). Between the three municipalities that form ABC Paulista, SCS has the highest EIR, about 2,079 (Fig. 7 and Fig. 8). This reflects a high dependence of this urban system on purchased resources. A system driven by outside resources (be they renewable or not) is never "sustainable", although it can somehow be stable for a relatively long time, depending on the stability of the flow of resources from outside (Ascione et al., 2009).

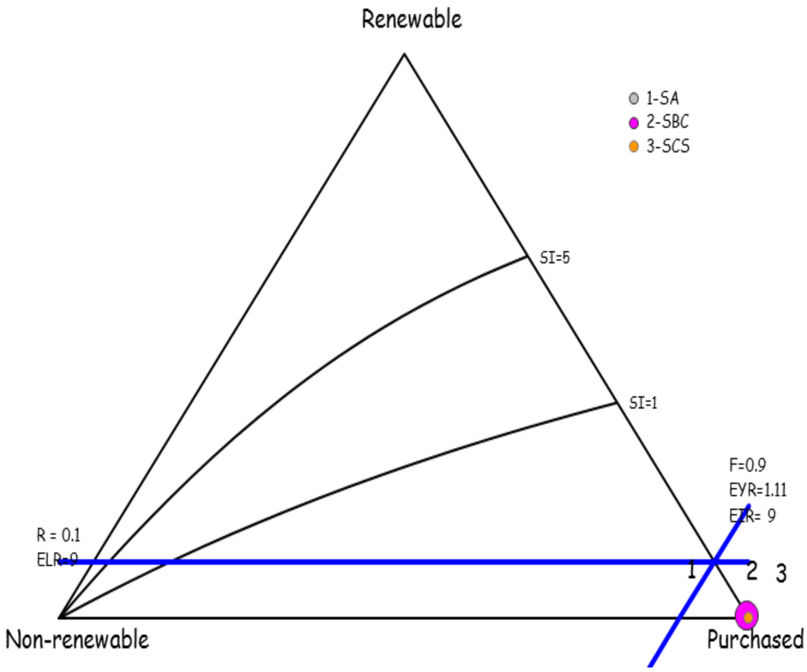

Fig. 7 – Emergetic ternary diagram of the municipalities of ABC Paulista.

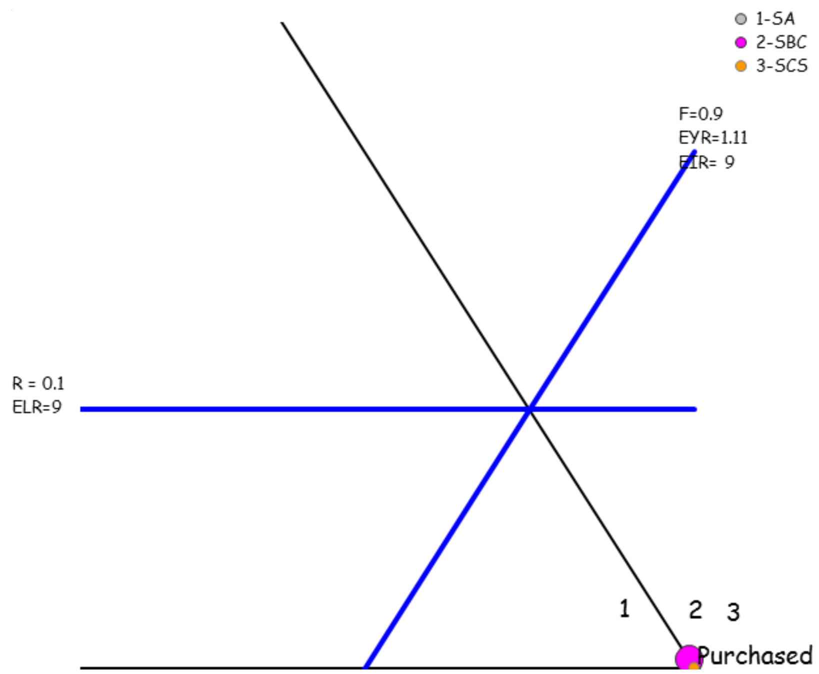

Fig. 8 – Zoom of the emergetic ternary diagram of the municipalities of ABC Paulista showing the corner of purchased resources.

The ELR value of ABC Paulista has a similar value to the EIR, due to the fact that in the calculations, the non-renewable resources are so small that the difference is almost not realized. The ELR value of 363 (Fig. 7; Table 7, line 23) indicates a highly stressed environment. The ELR value of SCS is exactly the same of EIR (about 2,079) since SCS has no non-renewable resources. This value indicates an even more stressed environment. The environment stress can be observed also by an economical perspective. SCS has an area of 15 km^2 and its GDP is 4,460,101 thousand USD. If these values are compared with the values of the other municipalities of ABC, it is possible to affirm that the industrial activity in SCS is extremely intensive. SCS has almost 12 times less area than SA, but its GDP compared to the SA's GDP is not even two times lower.

Table 8 shows that the more intense the economic activity, the higher will be the environmental stress.

Table 8 – Comparison between the municipalities and ABC regarding GDP/area values

	SA	SBC	SCS	ABC
GDP/area (USD/m^2)	42.03	35.64	297.34	44.10
GDP/capita (USD/inhabit.)	10,921.96	17,840.02	29,324.82	16,061.59
ELR	466.95	260.55	2,078.79	362.94

The ELR calculated for Rome (60.43) (Ascione et al., 2009) should be compared with the ELR of ABC. ABC has a well-known industrial activity (that should indicate a much stressed environment), and this is revealed by its ELR (362.94), 6 times higher than Rome. Rome is a municipality that counts with rural areas and the tourism is the major economic activity. The results of this study show clearly that ABC is a center that transforms flows to give support to other places.

The EYR values for ABC (EYR = 1.003) and its municipalities are basically the same (Fig. 7; Table 7, line 24). The values slightly higher than one mean that this urban system does not provide significant net emergy to the economy and only transform resources that are already available from previous processes. In doing so it acts as consumption/conversion process instead of making new resources available for system's growth. It is interesting to note that, despite the different characteristics, the small value of the EYR of Rome (1.02) also shows that the city is simply a consumer system, without any possibility of relying on local resources. The Italian system as a whole (1.29) relies much more on local resources (agriculture, minerals, hydroelectricity, etc.). Ascione et al. (2009) point out that Italy can provide resources to Rome. In the case of ABC, the EYR of the state of São Paulo is 2.36 and Brazil is 6.84 (Demétrio, 2011). This shows that either São Paulo state, as well as Brazil have more resources to provide to a urban system like ABC and that in long term, ABC has more conditions to maintain itself relying on state or national resources.

The ESI values (Fig. 7 and Fig. 8; Table 7, line 25) are for ABC and its municipalities very low, a lot lower than 1, which establishes the line between not sustainable in a long term and sustainable for medium term. This indicates that this urban system is not sustainable in a long term. This is not something exclusive of the municipalities of ABC Paulista. Other urban systems studies have shown similar values. 0.02 for Rome (Italy) (Ascione et al., 2009); 0.44 for

Siena (Italy) (Pulselli et al. 2008); 0.001 for Macao (China) (Lei et al., 2008); 0.004 for Taipei (Taiwan) (Huang and Hsu, 2003).

5.2. The ABC's analysis of renewable resources

The contribution of local renewable resources accounts for 0.3% of the total emergy that supports the ABC system. Observing the emergy signature for renewable resources shown in Fig. 9, it can be noted that the largest value for the renewable resources is the chemical energy of the rain in green areas, 86% of the total renewable resources for SA and 91% for SBC, which has a green area approximately three times larger than in SA. When it comes to SCS, the largest contribution from local energy is due to geothermal heat, since SCS has no green area.

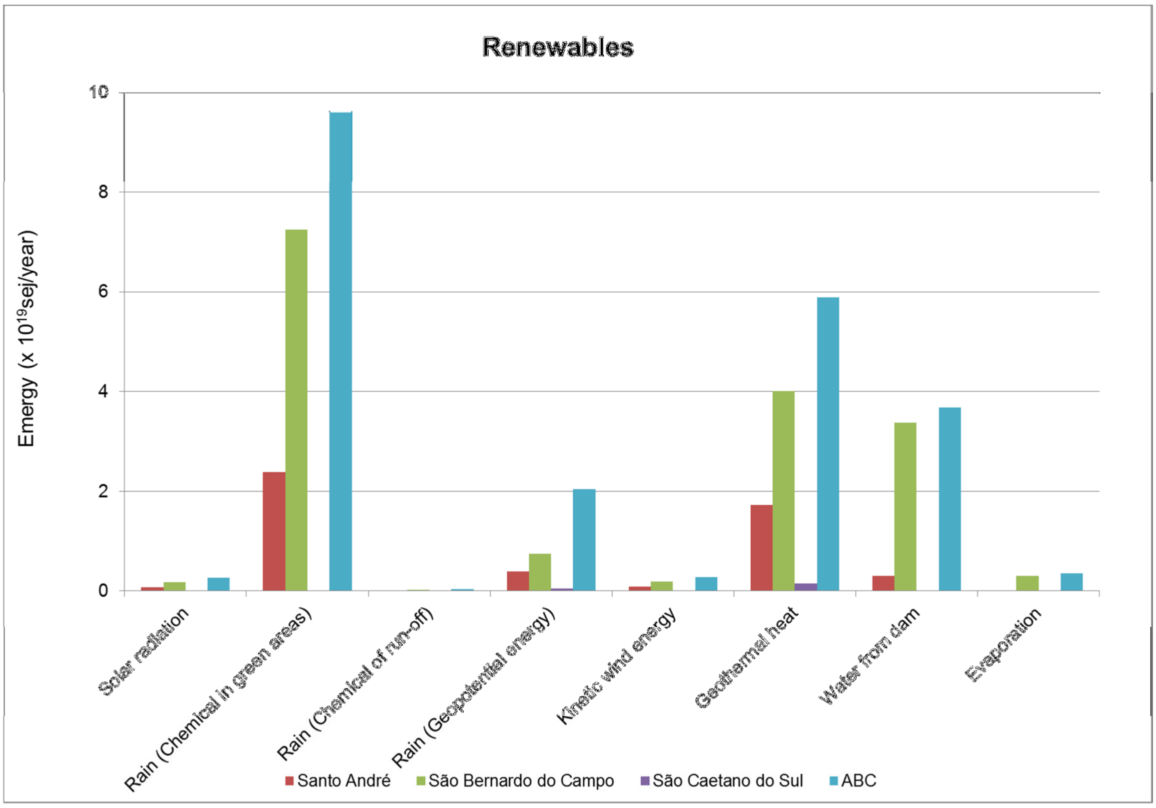

Fig. 9 – Emergy signature of renewable resources for Santo André, São Bernardo do Campo, São Caetano do Sul and ABC.

Due to its location and to the growth of the cities around it, SCS occupies a disadvantageous position with respect to the availability of renewable resources (Fig. 10). This municipality counts with 18 times less renewable resources than SA, and 53 times less resources than SBC. The city is surrounded by a heavy urbanized part of São Paulo municipality, and the most urbanized areas of SBC and SA. Thus, the environmental support of SCS relies on those provided by the surroundings municipalities.

Since SCS does not count with rural areas, it does not receive contributions of local non-renewable resources. SCS uses environmental services from the neighbor municipalities, that are not accounted in its emergy table (Appendix B), such as green areas to preserve its climate conditions and CO_2 absorption. This municipality can be assigned as an extreme urban consumer system, with no possibility of relying on local resources. There are interactions between two cities that does not include only raw material flow, transportation, water flow, labor transfer, goods flow, mineral flow, but also the use, proper or not, of environmental services (Chen and Chen, 2011).

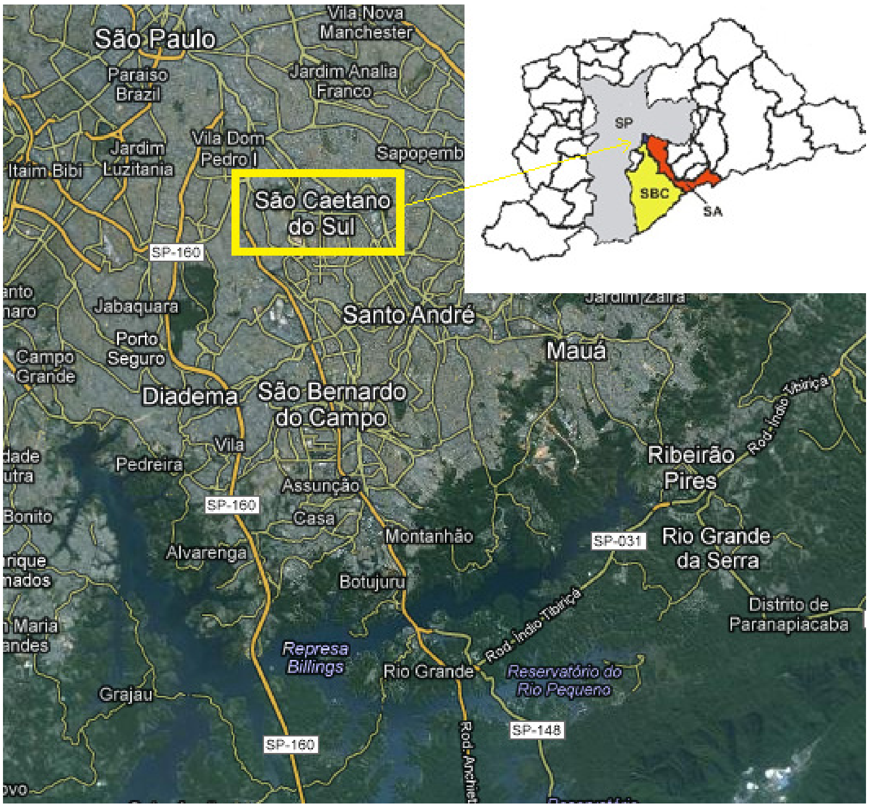

Fig. 10 – Location of São Caetano do Sul in relation to Santo André, São Bernardo do Campo and São Paulo.

5.3. The ABC's analysis of imported resources

All three municipalities are similar in that they are all highly dependent on the import of goods, electricity and fuels. Observing the municipalities individually, SA uses about 99.8% of purchased resources, SBC about 99.6%, while SCS reaches almost 100% of resources that come from other regions.

The dominance of human-controlled input flows (fuel, goods, labor, and services) from outside is impressive, compared to locally available free renewable and non-renewable resources. The complexity of this urban system is mostly driven by non-renewable imports, which makes the system highly unsustainable and dependent on fossil fuels and a fossil fuel-based economy. In principle, such a result is not new thanks to previous studies on energy and material dependence of urban systems, some of which are cited in the bibliographic review. However, converting raw amounts of resources into emergy units allows a comparison among flows of different natures and, most of all, changes the relative weight of flows compared to each other. The relative importance of food, electricity and labor is comparable or even larger than direct fuel and electricity use. Traditional energy or embodied energy evaluations only point out that the use of fossil fuels is very large, but they are unable to quantify how large is the appropriation of environmental support and services by the urban system in the form of flows characterized by relatively lower energy content.

When it comes to the resources that come from outside ABC (imports 99.7% sej/sej), services embodied in the imports from outside Brazil contributes 37.5% to the total emergy, both followed by electricity (14.7% sej/sej) and fuels (8.5% sej/sej). Regarding agriculture goods (Fig. 11) that correspond to 8.1% of total emergy the ABC's municipalities, it is clear that this high value is due to the fact that very few resources are produced in the ABC's rural areas, which was not accounted for in this study.

The emergy signature shown in Fig. 11 does not include services to provide a better view of all the other imported resources. As mentioned above, SCS is seen as an extreme consumer. But even SA and SBC, that have considerable green area (around 36% and 47% respectively) and water dam inside its boundaries, are almost totally dependent on imported resources.

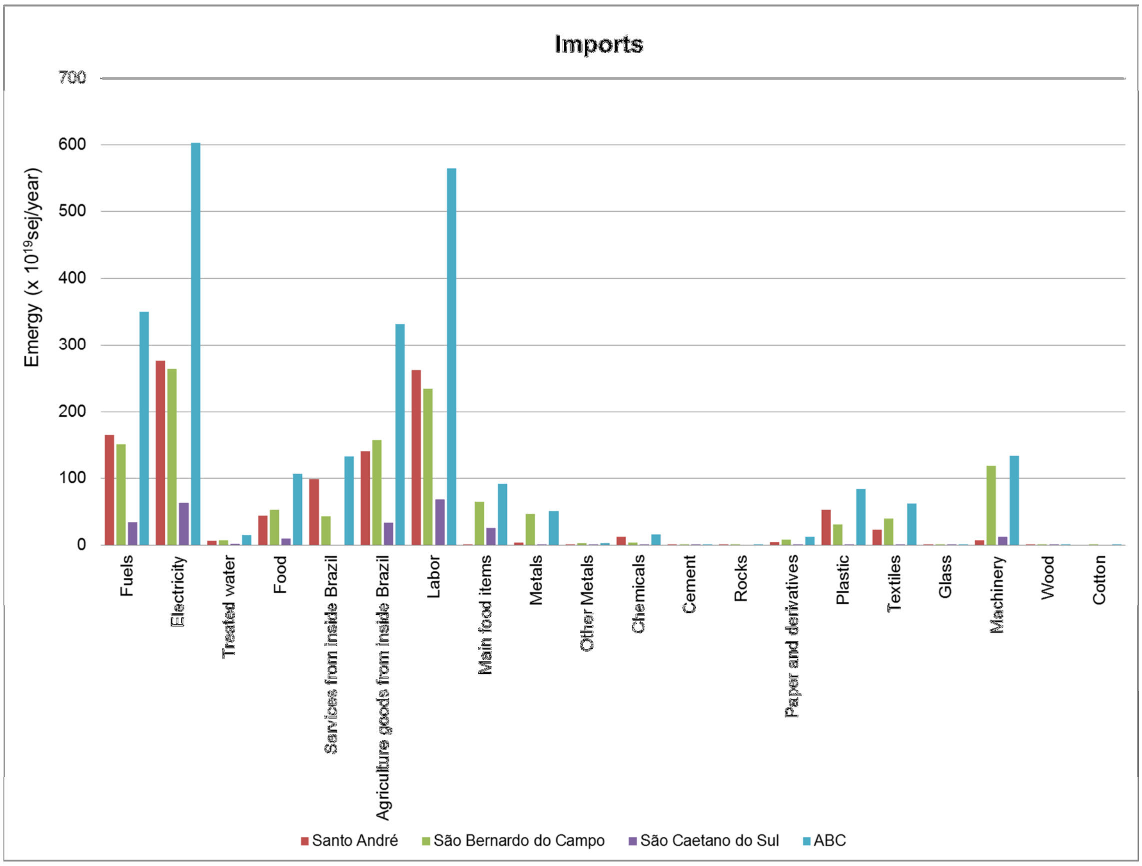

Fig. 11 – Emergy signature of the imported resources for Santo André, São Bernardo do Campo, São Caetano do Sul and ABC.

5.3.1 Electricity use

The electricity use (Fig. 12) is more pronounced in SA contributing with 19.0% of the total emergy, from which almost 68% is used by the industrial sector. In SBC the electricity contributes 11.6% to the total emergy (with 61% of which due to the industrial sector, Appendix B). In SCS the contribution of the electricity is 16.2%, and the industrial sector corresponds to almost 50% of this value (Appendix B). Assuming that commercial activities are performed by the population that lives in each municipality, the electricity use per capita can be calculated by the sum of residential, commercial and public lighting uses. It is interesting to note that SCS has the highest value of electricity use per capita (discounted the industrial sector) (Table 9), which may suggest that its population has a better life quality regarding access to the modern life facilities.

The results of the electricity use per capita can be compared to the HDIs values (Table 1). SCS has the highest HDI between the three municipalities, (0.919) and the highest electricity use per capita (2.09 x 10^{15} sej/yr person). The

HDIs are very similar for SA and SBC (0.835 and 0.834 respectively), and a similar result is observed through the calculations of electricity use per capita (1.33 x 10^{15} and 1.27 x 10^{15} sej/yr person respectively).

Observing ABC as a whole, electricity accounts for 14.7% of the total emergy, and industrial sector corresponds to 63% of the total electricity consumed by this group of cities. This result shows that the industrial sector is responsible for a great share of the energy consumption and suggests that a large fraction of resources consumed by these municipalities is not used by the local population, but for the production of goods which are mostly exported to other regions (to the state, in the country and abroad). It is observed that SA industries consume more electricity than industries from SBC. This higher consumption could be related to the chemical industry that has strong activity inside SA.

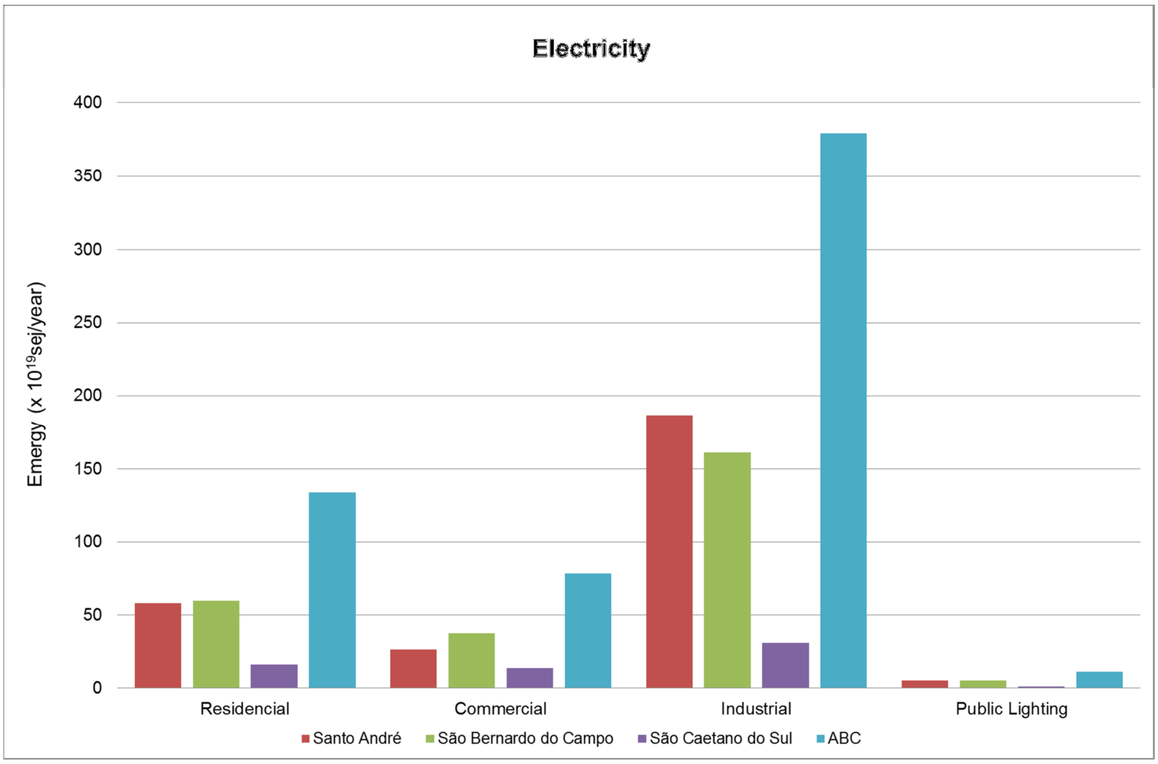

Fig. 12 – Emergy signature of electricity categorized by use for Santo André, São Bernardo do Campo, São Caetano do Sul and ABC.

Table 9 – Contributions of electricity to the total emergy and the use of the electricity per capita for Santo André, São Bernardo do Campo, São Caetano do Sul.

Electricity by use	SA	SBC	SCS
Residential	20.9%	22.6%	26.2%
Commercial	9.6%	14.3%	22.3%
Industrial	67.6%	61.1%	49.6%
Public Lighting	1.9%	2.0%	1.9%
Emergy per capita (sej/yr person)(*)	1.33×10^{15}	1.27×10^{15}	2.09×10^{15}

(*) excluded the Industrial sector

5.3.2 Fuel use

Observing the fuel consumption, the highest fuel consumer is SA. The emergy signature regarding fuels can be better understood detailing the fuels by types as shown in Fig. 13, which allows understanding why the emergy related to fuels in SA is higher than SBC. The consumption of natural gas (in terms of volume) in SA is almost three times higher than in SBC. This higher value of consumption of natural gas, related to the chemical industry strong activity, generates a higher total emergy value for fuels at SA.

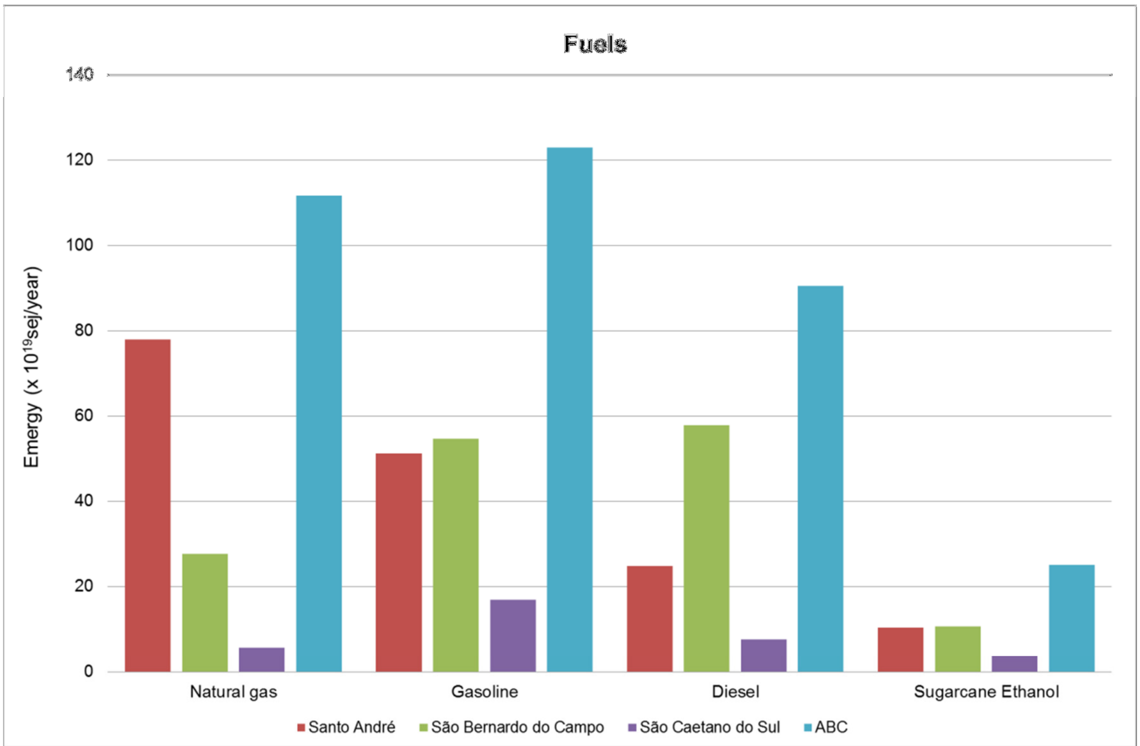

Fig. 13 – Emergy signature of fuels by type for Santo André, São Bernardo do Campo, São Caetano do Sul and ABC.

5.3.3 Labor

As expected, labor is one of the biggest contributors of emergy for ABC Paulista (almost 14% of the total emergy). Since ABC is inside a highly dense metropolitan area, the exchanges of workers are very intense due to the proximity among cities of greater São Paulo. SA, SBC and SCS hold high industrial and services activities and receive many workers from other their neighborhood, but also export a large number of workers to other municipalities (Table 10).

Table 10 – Labor exchange SA, SBC and SCS.

	People			
	Santo André	**São Bernardo do Campo**	**São Caetano do Sul**	**ABC**
Total population	673,396	810,979	152,093	1,636,468
Economic active population	334,951	379,259	77,816	792,026
Native workers	206,545	264,483	44,253	515,281
Percentage of native workers	61.7%	69.7%	56.9%	65.1%
Imported workers	128,406	114,776	33,563	276,745
Percentage of imported workers	38.3%	30.3%	43.1%	34.9%
Workers that work in other municipalities	124,505	109,791	32,491	266,787 (*)
Percentage of exported workers	37.2%	28.9%	41.8%	33.7%

(*) workers that work in other municipalities, other than Santo André, São Bernardo do Campo or São Caetano do Sul.
(IBGE - 2013 Data related to 2010 census)
Imported workers = Economic active population - Workers that work in other municipalities

SCS is the municipality with the smallest percentage of native workers (56.9%) and also the greatest percentage of imported workers (43.1%). These numbers reinforces the high dependence of SCS in all aspects.

5.4. The ABC's analysis of exported resources

The emergy signature shown in Fig. 14 does not include services (which correspond to 45.2% of the total exported emergy for ABC as a whole) and gives a better view of all the other exported goods. It is shown that the major exports of ABC to outside Brazil correspond to machinery (more concentrated in SBC), plastic goods (more concentrated in SA) and textiles (more concentrated in SA).

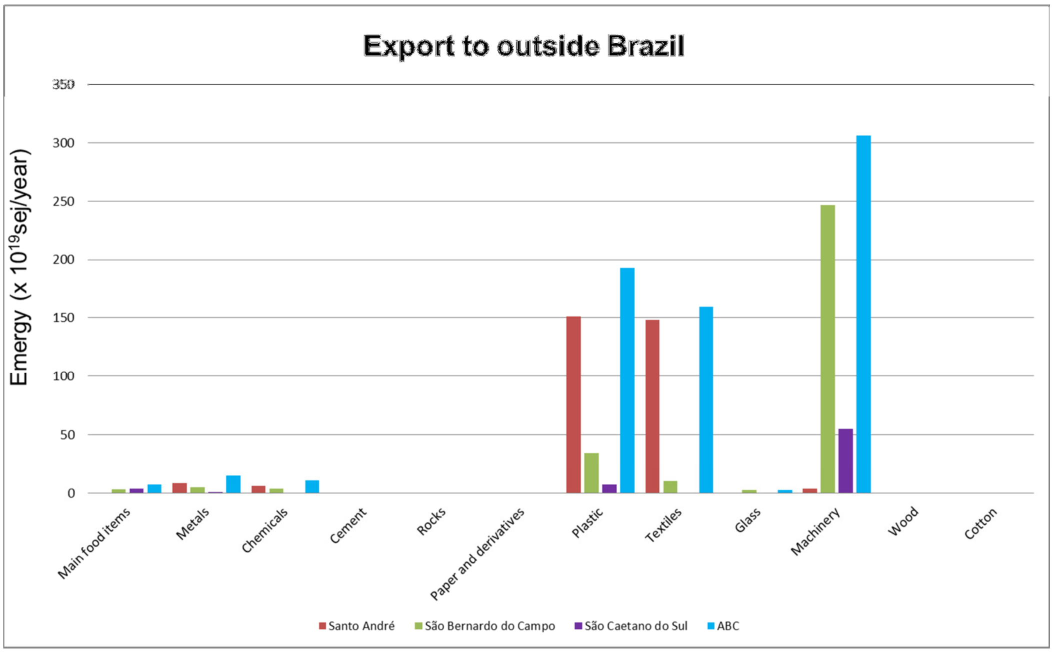

Fig. 14 – Emergy signature of exports from Santo André, São Bernardo do Campo, São Caetano do Sul and ABC to outside Brazil.

In the machinery sector, SBC responds to almost 89% of exports of ABC as a whole (to outside Brazil). When it comes to plastics and textiles together, SA responds to almost 85% of exports of ABC.

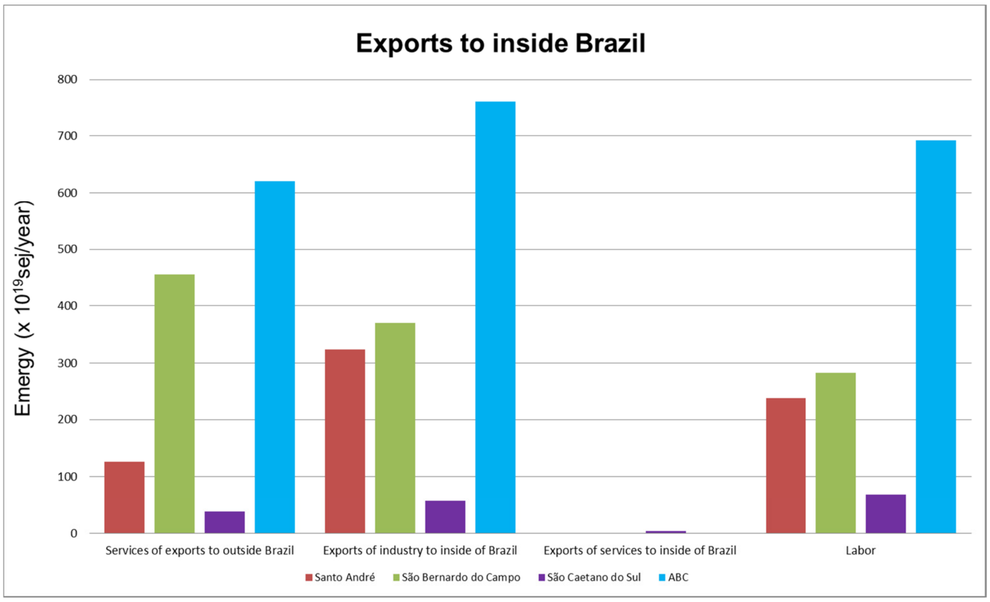

Fig. 15 – Emergy signature of exports from Santo André, São Bernardo do Campo, São Caetano do Sul and ABC to inside Brazil.

Among the exports to inside Brazil, services embodied in the exports, as well as labor are the largest exports (Fig. 15).

The emergy of total exports corresponds to almost 68% of the ABC's total emergy. SA individually exports 69.2% of its total emergy, SBC 62.2% and SCS 60.8% (Appendix B).

Exports refer to selling goods and services produced to other markets, and are a measure of the total physical movement of goods and services out of each municipality. Since none of the three municipalities count with natural reserves of raw material to be used in industries, it was assumed that exports depend on the resources (materials and energy) that enter the municipalities, and are transformed within their boundaries with the aid of local or imported labor. By the observation of the percentages of exports, it is possible to suggest that the population of SCS is the one which makes the higher use of the resources it receives, both from nature and external economies.

SBC exports 62.2% of its total emergy with a GDP of 1.45×10^{10} USD per year, while SA exports 69.2% of its total emergy with a GDP of 7.35×10^{9} USD per year. This result may indicate that energy and materials are used in the municipality, but also that products and services exported have low economic value. SBC exports 1.25 times more emergy in goods and services than SA (Table 6). SCS exports 60.8% of its total emergy, and the money received for exports corresponds to 2.95×10^{8} USD per year (Table 6).

The external commerce tables from each municipality obtained from SECEX (Government Department of External Commerce), even accounting only the exports, shall reveal some other characteristics of the industrial activity that is held in each municipality. SA has as its major exported product (25% of total exports) tires for buses or trucks followed by tires for automobiles (12% of total exports). SBC has as its major exported product (13% of total exports) chassis with motors for vehicles that transport more than 10 people followed by automobiles (9% of total exports). SCS has as its major exported product (24% of total exports) automobiles with motors between 1500 and 3000 cm^3 followed by automobiles parts (8% of total exports).

The evaluation of the emergy tables of the three municipalities that compose the ABC Paulista suggests that the cities underwent a process of auto-organization, in which each city has specific activities that may complement the activities of their neighbors.

Together, the three systems support each other. SCS depends on the natural resources of SA, SBC and other neighbor municipalities, but provides services and housing for people who work in nearby cities. For the electricity use per capita value (Table 9), discounting the use of the industrial sector) and the value of the HDI is possible to suggest that the services exported by SCS are of high quality. SA imports less service (31.3% of the total emergy) than SBC and SCS, which may indicate the availability to its own use or to export. SBC imports 47.9% of its total emergy and its exported services accounts for 20% of its total emergy.

As pointed out earlier, the economy of ABC can be considered as a subsystem of the state economy, functioning as a subsidiary economy within it. Materials and energy are imported, transformed and exported to the benefit to the greater systems (São Paulo, Brazil or abroad).

An emergy benefit-to-seller or benefit-to-purchaser ratio was calculated to analyze the emergy benefits that accrue to ABC as a result of exportation. Roughly considering that the total GDP of each municipality is due to exports, that is, that exports provide all currency that circulates in ABC, the calculation in Table 11 illustrates the comparison of all export emergy to the emergy of money circulating in these economies.

Table 11 – Emergy benefit ratios of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC.

	Santo André	**São Bernardo do Campo**	**São Caetano do Sul**	**ABC**
GDP (USD/year)	7.35×10^{09}	1.45×10^{10}	4.46×10^{09}	2.63×10^{10}
EMR (sej/USD)	1.98×10^{12}	1.58×10^{12}	8.75×10^{11}	1.56×10^{12}
Emergy of total exports (sej/year)	1.01×10^{22}	1.42×10^{22}	2.37×10^{21}	2.77×10^{22}
Money received by total exports(*)	2.27×10^{09}	5.24×10^{09}	1.09×10^{09}	8.84×10^{09}
Emergy of money received by total exports	4.49×10^{21}	8.28×10^{21}	9.54×10^{21}	1.38×10^{22}
Emergy of the GDP (sej/year)	1.46×10^{22}	2.29×10^{22}	3.90×10^{21}	4.10×10^{22}
Money received by internal exports (**)	1.64×10^{09}	2.35×10^{09}	6.94×10^{08}	4.87×10^{09}
Emergy of money received by internal exports	3.25×10^{21}	3.71×10^{21}	6.07×10^{20}	7.60×10^{21}
Emergy of internal exports	5.36×10^{21}	6.53×10^{21}	1.08×10^{21}	1.32×10^{22}
Money received by external exports (***)	6.35×10^{08}	2.89×10^{09}	4.40×10^{08}	3.97×10^{09}
Emergy of money received by external exports	1.26×10^{21}	4.57×10^{21}	3.85×10^{20}	6.19×10^{21}
Emergy of external exports	4.45×10^{21}	7.65×10^{21}	1.30×10^{21}	1.45×10^{22}
Emergy benefit ratio (considering GDP)	**0.694**	**0.621**	**0.607**	**0.676**
Emergy benefit ratio (considering total exports)	**2.247**	**1.715**	**2.485**	**2.009**
Emergy benefit ratio (considering internal exports)	**1.651**	**1.759**	**1.779**	**1.737**
Emergy benefit ratio (considering external exports)	**3.539**	**1.675**	**3.377**	**2.341**

Detailed calculations are available in Appendix H.
(*) Exports (internal + external) of the municipality or ABC to the rest of Brazil and the world.
(**) Exports (only internal) of the municipality or ABC to the rest of Brazil.
(***) Exports (only external) of the municipality or ABC to the rest of the world.

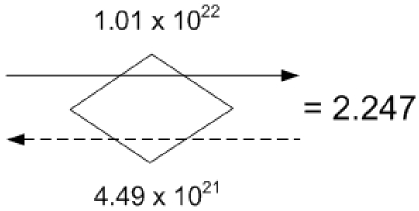

Fig. 16 – Calculation of the emergy benefit ratio for ABC considering total exports.

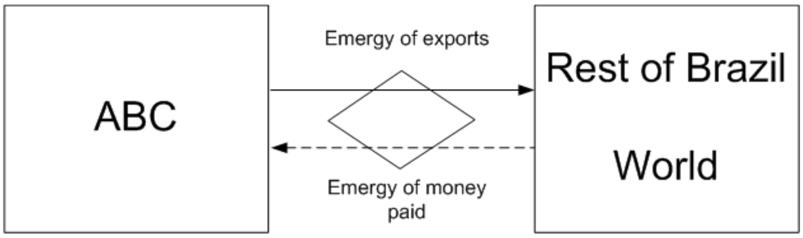

Fig. 17 – Exchanges between ABC and the rest of Brazil / World.

Considering that all the money circulating in the municipalities is provided by exports, product emergy leaving the ABC was 2.77 x 10^{22} sej/year while the emergy of money circulating into the municipalities in exchange would be only 4.10 x 10^{22} sej for the same year. The benefit-to-seller ratio for ABC would be 0.676 (Fig. 16). This indicates that if all GDP of ABC was composed by exports, the urban agglomerate would receive 1 sej for every 1.48 sej received as emergy for money paid. In other words, in terms of emergy, ABC would be benefited by its exports. However, not all the GDP comes from exports.

A much more real situation would be performing the same calculation but now using the real money received by the exports.

In average, the money received by exports by the municipalities corresponds to 30% of their GDP. Thus, the exchanges between ABC and the rest of the world are disadvantageous.

The ratio, 2.009, indicates that overall, ABC was exporting two times more emergy in goods and services than it would be receiving in the money paid for them. The city which shows the smallest disadvantage, which the one which exports more services is SBC. For improving economic and ecological sustainability, ABC (especially SA and SCS) should consider alternatives to their current export profile including the development of industrial products that could deliver an emergy benefit.

Another point of view would be that, if the exports correspond roughly to 30% of the GDP, then the rest (70%) would be related to internal transformations. These transformations could be related to the production of goods and services destined to the local population's welfare.

Observing the emergy benefit ratio considering only external exports and comparing it to the emergy benefit ratio considering only internal exports it is noted that ABC has less disadvantage when trading with the internal market (Brazil), than when trading with the rest of the world. The emergy benefit ratio of ABC for internal trading is 1.737, so Brazil takes advantage when buying from ABC. ABC delivers 1 sej and receives 0.575 sej when it exports to the Brazilian market. When ABC exports to the rest of the world, the emergy benefit ratio is 2.341. This indicates that ABC is even more disadvantageous when it trades with the external market. The relation between the delivered and received is now 1 sej to 0.427 sej.

The disadvantage found on trading with external markets can be partially explained by the values of EMR. Usually, Brazil buys from and sells to countries that have lower values of EMR, generally leaving the country in an unfavorable situation. On the other hand, the disadvantageous trade within the country was unexpected since EMR of Brazil is 3 times higher than that of ABC. Further studies considering the prices practiced in this trade are needed to explain the obtained result.

5.5. The ABC's storages

Systems store significant amounts of resources over time (for example, wood biomass in a forest ecosystem or buildings in a city). Materials and energy stored are used to increase the size and complexity of the system and, therefore, a full accounting of storages may help understanding the system. In order to calculate the emergy of stored resources, the emergy of each input multiplied by the time of its contribution is considered. Productive capital base or the capital stock of a region is made up of economic, natural, and social capitals (Table 12).

Table 12 – Emergy of the stocks of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC Paulista.

Type of stock (*)	Item	Indicator	Considered Turnover time (years)	Emergy of the stock (sej) ABC	SA	SBC	SCS
E	1	Building	25	3.26×10^{26}	1.34×10^{26}	1.86×10^{26}	6.39×10^{24}
N	2	Water from Billings dam	2.87	7.40×10^{17}	6.13×10^{16}	6.79×10^{17}	0.00×10^{00}
N	3	Biomass	-	2.39×10^{20}	4.22×10^{19}	1.97×10^{20}	0.00×10^{00}
N	3a	Forest	100	2.16×10^{20}	3.64×10^{19}	1.80×10^{20}	0.00×10^{00}
N	3b	Grass	3	2.28×10^{19}	5.78×10^{18}	1.71×10^{19}	0.00×10^{00}
E	4	Vehicle fleet	-	6.21×10^{22}	2.63×10^{22}	2.79×10^{22}	7.88×10^{21}
E	4a	Car	7	5.13×10^{22}	2.20×10^{22}	2.28×10^{22}	6.46×10^{21}
E	4b	Truck	10	6.20×10^{21}	2.43×10^{21}	2.99×10^{21}	7.78×10^{20}
E	4c	Pick-up truck	7	4.47×10^{21}	1.85×10^{21}	1.99×10^{21}	6.32×10^{20}
E	4d	Motorcycle	4	1.55×10^{20}	6.98×10^{19}	7.19×10^{19}	1.36×10^{19}
E	4e	Scooter	4	1.57×10^{19}	6.34×10^{18}	7.62×10^{18}	1.74×10^{18}
S	5	Population	70	1.64×10^{25}	6.79×10^{24}	8.07×10^{24}	1.52×10^{24}

Detailed calculations are available in Appendix E.
(*) E: Economic capital; N: Natural capital and S: Social capital

Three forms of capital must be considered simultaneously to address sustainability. Economic capital of ABC includes assets such as buildings, machinery, and infrastructure. Natural capital includes environmental functions such as provision of natural resources such as biomass and water to production and housing activities, but also for dissipation and absorption of wastes. Social capital includes human resources mainly. The criterion of strong sustainability considers that ecosystem goods and services cannot be replaced by human-made capital. It requires preservation of natural capital in itself, in addition to other capital stocks. The calculated emergy storages (Table 12) were converted into currency values by multiplying them by the EMR of each municipality (Table 13). This analysis may provide useful insight into the reliance of economic activity on natural capital and guide the development of effective policies and corporate decisions (Lou and Ulgiati 2013).

Table 13 – Economic values of emergy storages in ABC.

	Emdollar (Em$) Santo André	São Bernardo do Campo	São Caetano do Sul	ABC
Economic capital	2.66×10^{38}	2.94×10^{38}	5.60×10^{36}	5.65×10^{38}
Natural capital	8.37×10^{31}	3.12×10^{32}	0	3.96×10^{32}
Social capital	1.35×10^{37}	1.28×10^{37}	1.33×10^{36}	2.75×10^{37}
Total	$\mathbf{2.79 \times 10^{38}}$	$\mathbf{3.06 \times 10^{38}}$	$\mathbf{6.93 \times 10^{36}}$	$\mathbf{5.92 \times 10^{38}}$

The contribution of ecosystem goods and services to industrial activity is a measure of the sector's reliance on natural capital, but despite the green areas and the water dam that provide ecosystems services to the region, natural capital represents less than 1% of the total currency values in ABC. The major contributors to the value of storages are the built environment (approximately 95%) and the social capital with the remaining 5%. However, two aspects come to attention when the storages are evaluated in separate for each city. The first is that the fleet, despite the great quantity of material used for its construction corresponds to less than 1% of the economic capital (Appendix E). The other aspect is that the social capital of SCS corresponds to 19% of the total capital of this city, confirming that export of services is a major characteristic of this city.

5.6. Analysis of the support area of ABC

The renewable resource base and an environmental loading ratio (ELR) were proposed by Brown and Ulgiati (2001) as means for determining both long term and short term carrying capacity respectively. Expressed as a ratio of the amount of emergy received by the local economy to the amount that is exported, a positive emergy trade balance is suggested to maintain an economic investment or economic agglomerate like ABC. In this way, it is reasonable to question what would be the carrying capacity of the greater economy (São Paulo) that could justify the maintenance of ABC.

Analyzing the renewable support areas (Table 14) it is possible to observe that all the municipalities would require a much larger area than its actual area when it is imagined that the municipality would rely only on renewable resources. SA would need almost 526 times its actual area, SBC would need 284 times and SCS would need 2,521 times. ABC as a whole would need 377 times its actual area.

In this region, the original natural capital was the Atlantic forest. In order to calculate the quantity of region of original natural capital required to supply the actual need of theses urban arrangements, it was made an approximation according to the calculations of Siche et al., 2010, to estimate a compensation area with the same characteristics of the original environment. The calculation using the support area of Atlantic forest has shown results even higher. ABC would occupy 1,900 times more area than its actual area. Individually, SA would occupy 2,288 times more area, SBC 1,541 times and SCS 7,166 times more area than its actual area.

Table 14 – Indirect area or renewable support area ($SA_{(r)}$) and the support area required to balance the system of interest with the ELR of the region (state of São Paulo, Brazil and Atlantic forest).

Municipality	Santo André	São Bernardo do Campo	São Caetano do Sul	ABC Paulista
Real area (m^2)	1.75×10^{08}	4.06×10^{08}	1.50×10^{07}	5.96×10^{08}
$SA_{(r)}$ (m^2)	9.20×10^{10}	1.15×10^{11}	3.78×10^{10}	2.25×10^{11}
$SA_{(r\ atlantic\ forest)}$ (m^2)	4.00×10^{11}	6.26×10^{11}	1.08×10^{11}	1.13×10^{12}
$SA_{(ELR\ SP\ state)}$ (m^2)	1.38×10^{10}	1.73×10^{10}	5.67×10^{09}	3.37×10^{10}
$SA_{(ELR\ Brazil)}$ (m^2)	7.13×10^{10}	8.94×10^{10}	2.93×10^{10}	1.74×10^{11}

When it comes to the area required to balance the system of interest with the ELR of the region, something has to be pointed out. This concept is similar to an ecological footprint. Choosing the region is important as it affects the analysis. In some cases, the region might be a watershed, or market region. In other cases, it might be a political region like a state or nation. The choice of regional area is important, but there are no fixed criteria for establishing one (Brown and Ulgiati, 2001).

Considering that the regional area is the state of São Paulo, this would be the surrounding of this urban system. Then, ABC as a whole needs 56 times more area than its actual area. This occupation is due to the resources that would be taken from other parts of the state to provide resources to ABC.

Considering that the regional area is Brazil, than ABC would occupy 292 times more area than its actual area. This occupation is due to the resources that would be taken from other parts of the country to provide resources to ABC.

6. Conclusions

This work has applied the emergy synthesis to ABC Paulista and its municipalities. It has shown pioneer, and exclusive ways of calculations applied to the study of urban systems. The Shift-Share analysis is shown as a good way to estimate the exchanges between municipalities and the larger systems that in this case is Brazil. This tool is proposed as a scientific based method capable to solve the problem of lack of data that is particularly often when studying urban systems or even smaller systems.

The tables of the emergy accounting for SA, SBC and SCS have shown differences and similarities between them. SCS is characterized as an urban system that has a low value of renewable resources, its main stock is composed by built infrastructure (6.93×10^{36} Em$) and its main export is services and labor that together, account for 47% of the emergy of exports. SA and SBC have higher values of renewable resources, and the main stocks are also composed by building but in a much higher proportion to its social capital. The major exports for SA and SBC are manufactured goods related to automotive and chemical industry. When ABC is analyzed as a whole, SCS gets diluted, due to its size, and ABC shows results very similar to the ones of SA and SBC.

The emergy indices were calculated and have shown results that were already expected for urban systems. This can be clearly visualized in the emergetic ternary diagram. The indices also reinforce the differences between SCS compared to SA and SBC. The indices EYR (very close to 1.0), high values of EIR and high ELR show a typical picture of highly urbanized systems that hold industrial activities, services providing and housing infrastructure. These municipalities can be understood as emergy amplifiers. Raw materials or pre-assembled goods are received and transformed with the use of regional labor and services. Labor and services in the region hold know how and are highly specialized. In this way, the goods produced have higher transformities. In general terms it is possible to affirm that the municipalities combine material and information that almost always come from outside its boundaries, in order to produce high quality products.

The emergy signatures have shown the composition of the renewable resources, imported and exported goods for each municipality, confirming the scenario exposed by the emergy indices. An emergy benefit-to-purchase ratio was calculated to analyze the exports. The value calculated for ABC considering all the exports was 2.009. This means that trades of ABC are disadvantageous. In other words, ABC delivers 2 sej in products and services and receives 1 sej in monetary equivalents.

The internal transformations that occur inside each municipality could be related to the production of goods and services destined to the local population's welfare. Even if great part of the production is destined to export, it is unquestionable that it brings monetary richness to the municipality. These municipalities present a relatively high HDI and part of this is due to the availability of the modern conveniences provided by their urban centers. The high values of HDI and the unsustainability presented by the emergy synthesis show the differences between a narrow view of the system (HDI) and a wider and much more comprehensive view given by the emergy synthesis.

An emergy evaluation of the stocks was performed and the emergy value of each stock was estimated, as well as its monetary value. A very important stock of social capital was observed in SCS, reinforcing the fact that this is the municipality that exports more labor in ABC.

The support areas were calculated by two different methods. The renewable support area and renewable support area using NPP produced different results, but in both cases, it is observed that the municipalities require a much larger support area than its real area.

As expected, the emergy accounting has shown that ABC and its municipalities are not sustainable. This is not an exclusivity of ABC since many researchers have found similar results for diverse urban systems. Cities are not meant to be sustainable. Some action can improve its sustainability, but an urban system such as ABC will always require imported resources in a quantity much higher than its available local renewable and non-renewable resources. In this way, policies related to keep and maintain the support areas as well as the compensation areas, so that these urban structures can be conserved without damaging the global sustainability, are of major importance.

Urban agglomerates unsustainability is inherent, as well as their role in the larger system. Generally speaking, urban centers are the best known way to disperse new information efficiently. Innovation moves very rapidly into the city, and under this perspective, they are essential.

7. Suggestions for future work

The main suggestions for future work are:

- To quantify the ecological and economic interactions between the cities from ABC Paulista.

- To link this study to the automotive industry cluster that is placed in this region.

- To validate the method of Shift-Share analysis using urban systems with detailed and reliable data, capable to generate a calculation using the emergy accounting and a parallel one using the Shift-Share analysis.

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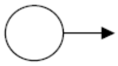
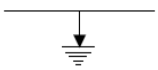
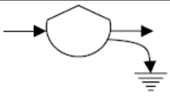
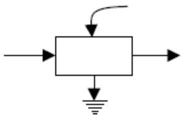
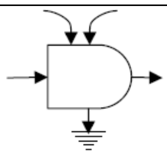
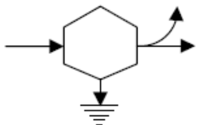
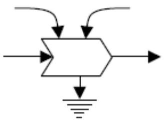
Appendix A

Table A1 – Main symbols for energy diagram construction

	**Arrow**: A pathway proportional to the quantity in the storage or source upstream. When the arrow is dashed it represents money flow.
	**Source**: Outside source of energy delivering forces according a program controlled from outside; a forcing function.
	**Heat sink**: Dispersion of potential energy into heat that accompanies all the real transformation processes and storages; loss of potential energy from further use by the system.
	**Tank**: A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.
	**Box**: Miscellaneous symbol to use for whatever unit or function is labeled.
	**Producer**: Unit that collects and transforms low intensity energy using a high quality energy flow.
	**Consumers**: Unit that uses and transforms the energy, stores it as higher quality energy and feedback energy (autocatalytic system) in order to improve the energy flow that is received.
	**Interaction**: Interactive interaction of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.

Appendix B

In this appendix, are presented complete emergy tables of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC.

Table B1 – Matter, energy and emergy flows supporting Santo André.

	Item	Units	Quantity	UEV (sej/unit)	Emergy $\times 10^{19}$ (sej/year)	Percentage of the total emergy
Local renewable resources						
1	Solar radiation	J/yr	7.73×10^{17}	1	0.08	<0.1%
2	Rain (Chem. energy in green areas) (*)	J/yr	7.67×10^{14}	3.10×10^{04}	2.38	0.2%
3	Rain (Chem. energy of run-off) (*)	J/yr	3.48×10^{12}	3.10×10^{04}	0.01	<0.1%
4	Rain (Geopotential energy) (*)	J/yr	8.19×10^{13}	4.70×10^{04}	0.39	<0.1%
5	Kinetic wind energy	J/yr	3.33×10^{14}	2.45×10^{03}	0.08	<0.1%
6	Geothermal heat	J/yr	2.98×10^{14}	5.80×10^{04}	1.73	0.1%
7	Water use from Billings dam	m^3/yr	8.01×10^{06}	3.81×10^{11}	0.31	<0.1%
8	Evaporation	m^3/yr	9.96×10^{04}	2.44×10^{11}	0.00	<0.1%
	Total of renewable resources (**)				**2.76**	**0.2%**
Local non-renewable resources						
	Topsoil loss	J/yr	2.26×10^{11}	1.24×10^{05}	0.00	<0.1%
	Total of non-renewable resources				**0.00**	**<0.1%**
Imports from inside Brazil						
10	Fuels (Total)	J/yr	--	--	164.57	11.3%
10a	Natural gas	J/yr	1.14×10^{16}	6.84×10^{04}	78.03	5.4%
10b	Gasoline	J/yr	4.63×10^{15}	1.11×10^{05}	51.33	3.5%
10c	Diesel	J/yr	2.23×10^{15}	1.11×10^{05}	24.76	1.7%
10d	Sugarcane Ethanol	J/yr	2.15×10^{15}	4.87×10^{04}	10.45	0.7%
11	Electricity (Total)	J/yr	9.97×10^{15}	2.77×10^{05}	276.23	19.0%
11a	Residential	J/yr	2.08×10^{15}	2.77×10^{05}	57.74	4.0%
11b	Commercial	J/yr	9.58×10^{14}	2.77×10^{05}	26.56	1.8%
11c	Industrial	J/yr	6.74×10^{15}	2.77×10^{05}	186.76	12.8%
11d	Public Lighting	J/yr	1.86×10^{14}	2.77×10^{05}	5.16	0.4%
12	Treated water	L/yr	4.14×10^{10}	1.55×10^{09}	6.43	0.4%
13	Food	J/yr	3.09×10^{15}	1.43×10^{05}	44.08	3.0%
14	Services from inside Brazil	USD/yr	2.07×10^{08}	4.78×10^{12}	99.05	6.8%
15	Agriculture goods from inside Brazil	USD/yr	2.95×10^{08}	4.78×10^{12}	141.06	9.7%
16	Labor	kg/yr	1.28×10^{05}	2.04×10^{16}	261.95	18.0%
	Total of Imports from inside Brazil (F_{int}) with services				**993.35**	**68.2%**
	Total of Imports from inside Brazil (F_{int}) without services				**894.31**	
Imports from outside Brazil						
17	Main food items (Total)	kg/yr	--	--	1.16	0.1%
17a	Cereals and derivatives	kg/yr	5.04×10^{05}	6.04×10^{11}	0.03	<0.1%
17b	Fish	kg/yr	1.59×10^{04}	2.78×10^{14}	0.44	<0.1%
17c	Meat	kg/yr	1.62×10^{04}	3.00×10^{13}	0.05	<0.1%
17d	Milk, cheese and other derivatives	kg/yr	4.14×10^{05}	1.44×10^{13}	0.60	<0.1%
17e	Fruits and vegetables	kg/yr	4.29×10^{05}	1.01×10^{12}	0.04	<0.1%
17f	Wine and alcoholics	kg/yr	0.00×10^{00}	1.41×10^{12}	0.00	0.0%
17g	Coffee	kg/yr	0.00×10^{00}	6.10×10^{11}	0.00	0.0%
17h	Sugar	kg/yr	0.00×10^{00}	2.98×10^{12}	0.00	0.0%
18	Metals (Total)	kg/yr	--	--	3.64	0.2%
18a	Aluminum	kg/yr	1.16×10^{06}	7.76×10^{11}	0.09	<0.1%
18b	Cooper	kg/yr	8.30×10^{05}	3.36×10^{12}	0.28	<0.1%
18c	Steel and Iron	kg/yr	4.61×10^{06}	3.16×10^{12}	1.46	0.1%
18d	Gold	kg/yr	1.12×10^{03}	1.50×10^{16}	1.68	0.1%
18e	Other Metals	kg/yr	8.41×10^{05}	1.54×10^{12}	0.13	<0.1%
19	Chemicals	kg/yr	1.92×10^{08}	6.38×10^{11}	12.23	0.8%

20	Cement	kg/yr	6.40×10^{05}	2.20×10^{12}	0.14	<0.1%
21	Rocks	kg/yr	1.35×10^{06}	1.64×10^{09}	0.00	<0.1%
22	Paper and derivatives	kg/yr	6.42×10^{06}	6.55×10^{12}	4.20	0.3%
23	Plastic	kg/yr	5.49×10^{07}	9.68×10^{12}	53.19	3.7%
24	Textiles	kg/yr	1.67×10^{06}	1.34×10^{14}	22.44	1.5%
25	Glass	kg/yr	3.62×10^{03}	3.50×10^{12}	0.00	<0.1%
26	Machinery	kg/yr	5.89×10^{06}	1.12×10^{13}	6.59	0.5%
27	Wood	kg/yr	2.43×10^{04}	6.79×10^{11}	0.00	<0.1%
28	Cotton	kg/yr	0.00×10^{00}	2.10×10^{13}	0.00	0.0%
29	Services of imports from outside Brazil	USD/yr	4.54×10^{08}	Diverse	356.22	24.5%
	Total of imports from outside Brazil (F_{ext}) with services				**459.81**	**31.6%**
	Total of imports from outside Brazil (F_{ext}) without services				**103.59**	
	Total of imports (internal+external) with services				**1,453.16**	**99.8%**
	Total of imports (internal+external) without services				**997.90**	
Exports to outside Brazil						
30	Main food items (Total)	kg/yr	--	--	0.09	
30a	Cereals and derivatives	kg/yr	9.25×10^{03}	6.04×10^{11}	0.00	
30b	Fish	kg/yr	4.87×10^{02}	2.78×10^{14}	0.01	
30c	Meat	kg/yr	0.00×10^{00}	3.00×10^{13}	0.00	
30d	Milk, cheese and other derivatives	kg/yr	4.20×10^{01}	1.44×10^{13}	0.00	
30e	Fruits and vegetables	kg/yr	1.13×10^{04}	1.01×10^{12}	0.00	
30f	Wine and alcoholics	kg/yr	1.37×10^{03}	1.41×10^{12}	0.00	
30g	Coffee	kg/yr	7.79×10^{03}	6.10×10^{11}	0.00	
30h	Sugar	kg/yr	2.44×10^{05}	2.98×10^{12}	0.07	
31	Metals (Total)	kg/yr	--	--	8.82	
31a	Aluminum	kg/yr	2.37×10^{06}	7.76×10^{11}	0.18	
31b	Cooper	kg/yr	1.08×10^{07}	3.36×10^{12}	3.62	
31c	Steel and Iron	kg/yr	9.63×10^{05}	3.16×10^{12}	0.30	
31d	Gold	kg/yr	3.14×10^{03}	1.50×10^{16}	4.71	
31e	Other Metals	kg/yr	0.00×10^{00}	1.54×10^{12}	0.00	
32	Chemicals	kg/yr	1.02×10^{08}	6.38×10^{11}	6.52	
33	Cement	kg/yr	4.03×10^{03}	2.20×10^{12}	0.00	
34	Rocks	kg/yr	8.00×10^{03}	1.64×10^{09}	0.00	
35	Paper and derivatives	kg/yr	1.67×10^{03}	6.55×10^{12}	0.00	
36	Plastic	kg/yr	1.56×10^{08}	9.68×10^{12}	151.22	
37	Textiles	kg/yr	1.11×10^{07}	1.34×10^{14}	148.13	
38	Glass	kg/yr	1.67×10^{03}	3.50×10^{12}	0.00	
39	Machinery	kg/yr	3.84×10^{06}	1.12×10^{13}	4.30	
40	Wood	kg/yr	4.50×10^{02}	6.79×10^{11}	0.00	
41	Cotton	kg/yr	9.60×10^{01}	2.10×10^{13}	0.00	
42	Services of exports to outside Brazil	USD/yr	6.35×10^{08}	1.98×10^{12}	125.72	
	Total of exports to outside Brazil with services				**444.81**	
	Total of exports to outside Brazil without services				**319.09**	
Exports to inside Brazil						
43	Exports of industry to inside Brazil	USD/yr	1.64×10^{09}	1.98×10^{12}	323.72	
44	Exports of services to inside Brazil	USD/yr	0.00×10^{00}	1.98×10^{12}	0.00	
45	Labor	people/yr	1.25×10^{05}	1.92×10^{16}	239.07	
	Total of exports to inside Brazil				**562.79**	
	Total of exports (internal+external) with services				**1,007.59**	
	Total of exports (internal+external) without services				**881.87**	
	Total Emergy				**1,455.93**	

(*) Rain was calculated as the sum of items 2 and the greatest value between items 3 or 4

(**) The total of renewable resources was calculated comparing the emergy value accounted for rain (explained above) with the sum of items 1 and 6. The greatest value between these two values was considered the total of renewable resources.

Detailed calculations are available in Appendix C.

Table B2 – Matter, energy and emergy flows supporting São Bernardo do Campo.

	Item	Units	Quantity	UEV (sej/unit)	Emergy x 10^{19} (sej/year)	Percentage of the total emergy
Local renewable resources						
1	Solar radiation	J/yr	1.79×10^{18}	1	0.18	<0.1%
2	Rain (Chem. energy in green areas) (*)	J/yr	2.34×10^{15}	3.10×10^{04}	7.25	0.3%
3	Rain (Chem. energy of run-off) (*)	J/yr	6.67×10^{12}	3.10×10^{04}	0.02	<0.1%
4	Rain (Geopotential energy) (*)	J/yr	1.57×10^{14}	4.70×10^{04}	0.74	<0.1%
5	Kinetic wind energy	J/yr	7.73×10^{14}	2.45×10^{03}	0.19	<0.1%
6	Geothermal heat	J/yr	6.91×10^{14}	5.80×10^{04}	4.01	0.2%
7	Water use from Billings dam	m^3/yr	8.86×10^{07}	3.81×10^{11}	3.38	0.1%
8	Evaporation	m^3/yr	1.22×10^{07}	2.44×10^{11}	0.30	<0.1%
	Total of renewable resources (**)				**7.98**	**0.4%**
Local non-renewable resources						
	Topsoil loss	J/yr	1.16×10^{12}	1.24×10^{05}	0.01	<0.1%
	Total of non-renewable resources				**0.01**	**<0.1%**
Imports from inside Brazil						
10	Fuels (Total)	J/yr	--	--	150.96	6.6%
10a	Natural gas	J/yr	4.05×10^{15}	6.84×10^{04}	27.68	1.2%
10b	Gasoline	J/yr	4.93×10^{15}	1.11×10^{05}	54.65	2.4%
10c	Diesel	J/yr	5.22×10^{15}	1.11×10^{05}	57.89	2.5%
10d	Sugarcane Ethanol	J/yr	2.21×10^{15}	4.87×10^{04}	10.75	0.5%
11	Electricity (Total)	J/yr	9.53×10^{15}	2.77×10^{05}	264.04	11.6%
11a	Residential	J/yr	2.15×10^{15}	2.77×10^{05}	59.71	2.6%
11b	Commercial	J/yr	1.36×10^{15}	2.77×10^{05}	37.83	1.7%
11c	Industrial	J/yr	5.82×10^{15}	2.77×10^{05}	161.31	7.1%
11d	Public Lighting	J/yr	1.87×10^{14}	2.77×10^{05}	5.19	0.2%
12	Treated water	L/yr	4.50×10^{10}	1.55×10^{09}	6.98	0.3%
13	Food	J/yr	3.72×10^{15}	1.43×10^{05}	53.08	2.3%
14	Services from inside Brazil	USD/yr	9.03×10^{07}	4.78×10^{12}	43.12	1.9%
15	Agriculture goods from inside Brazil	USD/yr	3.30×10^{08}	4.78×10^{12}	157.43	6.9%
16	Labor	kg/yr	1.15×10^{05}	2.04×10^{16}	234.14	10.3%
	Total of Imports from inside Brazil (F_{int}) with services				**909.77**	**39.9%**
	Total of Imports from inside Brazil (F_{int}) without services				**866.65**	
Imports from outside Brazil						
17	Main food items (Total)	kg/yr	--	--	65.30	2.9%
17a	Cereals and derivatives	kg/yr	3.16×10^{06}	6.04×10^{11}	0.19	<0.1%
17b	Fish	kg/yr	2.17×10^{06}	2.78×10^{14}	60.43	2.7%
17c	Meat	kg/yr	1.61×10^{04}	3.00×10^{13}	0.05	<0.1%
17d	Milk, cheese and other derivatives	kg/yr	2.80×10^{06}	1.44×10^{13}	4.04	0.2%
17e	Fruits and vegetables	kg/yr	3.81×10^{06}	1.01×10^{12}	0.39	<0.1%
17f	Wine and alcoholics	kg/yr	1.06×10^{06}	1.41×10^{12}	0.15	<0.1%
17g	Coffee	kg/yr	6.80×10^{05}	6.10×10^{11}	0.04	<0.1%
17h	Sugar	kg/yr	6.03×10^{04}	2.98×10^{12}	0.02	<0.1%
18	Metals (Total)	kg/yr	--	--	47.27	2.1%
18a	Aluminum	kg/yr	2.29×10^{05}	7.76×10^{11}	0.02	<0.1%
18b	Cooper	kg/yr	2.39×10^{06}	3.36×10^{12}	0.80	<0.1%
18c	Steel and Iron	kg/yr	1.77×10^{07}	3.16×10^{12}	5.61	0.2%
18d	Gold	kg/yr	2.54×10^{04}	1.50×10^{16}	38.14	1.7%
18e	Other Metals	kg/yr	1.75×10^{07}	1.54×10^{12}	2.70	0.1%
19	Chemicals	kg/yr	5.00×10^{07}	6.38×10^{11}	3.19	0.1%
20	Cement	kg/yr	4.97×10^{05}	2.20×10^{12}	0.11	<0.1%
21	Rocks	kg/yr	1.05×10^{06}	1.64×10^{09}	0.00	<0.1%
22	Paper and derivatives	kg/yr	1.20×10^{07}	6.55×10^{12}	7.83	0.3%
23	Plastic	kg/yr	3.13×10^{07}	9.68×10^{12}	30.29	1.3%
24	Textiles	kg/yr	2.96×10^{06}	1.34×10^{14}	39.67	1.7%
25	Glass	kg/yr	3.06×10^{06}	3.50×10^{12}	1.07	<0.1%
26	Machinery	kg/yr	1.02×10^{08}	1.12×10^{13}	118.80	5.2%
27	Wood	kg/yr	6.98×10^{05}	6.79×10^{11}	0.05	<0.1%

28	Cotton	kg/yr	1.68×10^{05}	2.10×10^{13}	0.35	<0.1%
29	Services of imports from outside Brazil	USD/yr	2.16×10^{09}	Diverse	1,047.72	46.0%
	Total of imports from outside Brazil (F_{ext}) with services				**1,361.65**	**59.7%**
	Total of imports from outside Brazil (F_{ext}) without services				**313.94**	
	Total of imports (internal+external) with services				**2,271.42**	
	Total of imports (internal+external) without services				**1,180.59**	
Exports to outside Brazil						
30	Main food items (Total)	kg/yr	--	--	3.71	
30a	Cereals and derivatives	kg/yr	3.63×10^{07}	6.04×10^{11}	2.20	
30b	Fish	kg/yr	0.00×10^{00}	2.78×10^{14}	0.00	
30c	Meat	kg/yr	4.86×10^{05}	3.00×10^{13}	1.46	
30d	Milk, cheese and other derivatives	kg/yr	1.19×10^{03}	1.44×10^{13}	0.00	
30e	Fruits and vegetables	kg/yr	1.07×10^{05}	1.01×10^{12}	0.01	
30f	Wine and alcoholics	kg/yr	2.64×10^{05}	1.41×10^{12}	0.04	
30g	Coffee	kg/yr	2.32×10^{03}	6.10×10^{11}	0.00	
30h	Sugar	kg/yr	1.33×10^{04}	2.98×10^{12}	0.00	
31	Metals (Total)	kg/yr	--	--	5.03	
31a	Aluminum	kg/yr	1.41×10^{06}	7.76×10^{11}	0.11	
31b	Cooper	kg/yr	1.34×10^{06}	3.36×10^{12}	0.45	
31c	Steel and Iron	kg/yr	4.51×10^{06}	3.16×10^{12}	1.42	
31d	Gold	kg/yr	9.30×10^{01}	1.50×10^{16}	0.14	
31e	Other Metals	kg/yr	1.89×10^{07}	1.54×10^{12}	2.90	
32	Chemicals	kg/yr	6.77×10^{07}	6.38×10^{11}	4.32	
33	Cement	kg/yr	2.19×10^{06}	2.20×10^{12}	0.48	
34	Rocks	kg/yr	2.08×10^{05}	1.64×10^{09}	0.00	
35	Paper and derivatives	kg/yr	9.84×10^{05}	6.55×10^{12}	0.64	
36	Plastic	kg/yr	3.58×10^{07}	9.68×10^{12}	34.64	
37	Textiles	kg/yr	7.72×10^{05}	1.34×10^{14}	10.35	
38	Glass	kg/yr	8.01×10^{06}	3.50×10^{12}	2.80	
39	Machinery	kg/yr	2.20×10^{08}	1.12×10^{13}	246.21	
40	Wood	kg/yr	1.04×10^{07}	6.79×10^{11}	0.71	
41	Cotton	kg/yr	2.10×10^{02}	2.10×10^{13}	0.00	
42	Services of exports to outside Brazil	USD/yr	2.89×10^{09}	1.58×10^{12}	455.78	
	Total of exports to outside Brazil with services				**764.67**	
	Total of exports to outside Brazil without services				**308.89**	
Exports to inside Brazil						
43	Exports of industry to inside Brazil	USD/yr	2.35×10^{09}	1.58×10^{12}	369.85	
44	Exports of services to inside Brazil	USD/yr	0.00×10^{00}	1.58×10^{12}	0.00	
45	Labor	people/yr	1.10×10^{05}	2.58×10^{16}	282.73	
	Total of exports to inside Brazil				**652.58**	
	Total of exports (internal+external) with services				**1,417.24**	
	Total of exports (internal+external) without services				**961.46**	
	Total Emergy				**2,279.42**	

(*) Rain was calculated as the sum of items 2 and the greatest value between items 3 or 4
(**) The total of renewable resources was calculated comparing the emergy value accounted for rain (explained above) with the sum of items 1 and 6. The greatest value between these two values was considered the total of renewable resources.
Detailed calculations are available in Appendix C.

Table B3 – Matter, energy and emergy flows supporting São Caetano do Sul.

	Item	Units	Quantity	UEV (sej/unit)	Emergy x 10^{19} (sej/year)	Percentage of the total emergy
Local renewable resources						
1	Solar radiation	J/yr	6.63×10^{16}	1	0.01	<0.1%
2	Rain (Chem. energy in green areas) (*)	J/yr	0.00×10^{00}	3.10×10^{04}	0.00	0.0%
3	Rain (Chem. energy of run-off) (*)	J/yr	4.65×10^{11}	3.10×10^{04}	0.00	<0.1%
4	Rain (Geopotential energy) (*)	J/yr	1.09×10^{13}	4.70×10^{04}	0.05	<0.1%
5	Kinetic wind energy	J/yr	2.86×10^{13}	2.45×10^{03}	0.01	<0.1%
6	Geothermal heat	J/yr	2.55×10^{13}	5.80×10^{04}	0.15	<0.1%
7	Water use from Billings dam	m^3/yr	0.00×10^{00}	3.81×10^{11}	0.00	0.0%
8	Evaporation	m^3/yr	0.00×10^{00}	2.44×10^{11}	0.00	0.0%
	Total of renewable resources (**)				**0.15**	**<0.1%**
Local non-renewable resources						
	Topsoil loss	J/yr	0.00×10^{00}	1.24×10^{05}	0.00	0.0%
	Total of non-renewable resources				**0.00**	**0.0%**
Imports from inside Brazil						
10	Fuels (Total)	J/yr	--	--	34.31	8.8%
10a	Natural gas	J/yr	8.43×10^{14}	6.84×10^{04}	5.77	1.5%
10b	Gasoline	J/yr	1.53×10^{15}	1.11×10^{05}	16.92	4.3%
10c	Diesel	J/yr	7.04×10^{14}	1.11×10^{05}	7.81	2.0%
10d	Sugarcane Ethanol	J/yr	7.84×10^{14}	4.87×10^{04}	3.82	1.0%
11	Electricity (Total)	J/yr	2.28×10^{15}	2.77×10^{05}	63.08	16.2%
11a	Residential	J/yr	5.95×10^{14}	2.77×10^{05}	16.50	4.2%
11b	Commercial	J/yr	5.08×10^{14}	2.77×10^{05}	14.09	3.6%
11c	Industrial	J/yr	1.13×10^{15}	2.77×10^{05}	31.26	8.0%
11d	Public Lighting	J/yr	4.42×10^{13}	2.77×10^{05}	1.23	0.3%
12	Treated water	L/yr	1.28×10^{10}	1.55×10^{09}	1.98	0.5%
13	Food	J/yr	6.97×10^{14}	1.43×10^{05}	9.95	2.5%
14	Services from inside Brazil	USD/yr	0.00×10^{00}	4.78×10^{12}	0.00	0.0%
15	Agriculture goods from inside Brazil	USD/yr	6.87×10^{07}	4.78×10^{12}	32.81	8.4%
16	Labor	kg/yr	3.36×10^{04}	2.04×10^{16}	68.47	17.5%
	Total of Imports from inside Brazil (F_{int}) with services				**210.60**	**53.9%**
	Total of Imports from inside Brazil (F_{int}) without services				**210.60**	
Imports from outside Brazil						
17	Main food items (Total)	kg/yr	--	--	25.63	6.6%
17a	Cereals and derivatives	kg/yr	1.77×10^{06}	6.04×10^{11}	0.11	<0.1%
17b	Fish	kg/yr	7.70×10^{05}	2.78×10^{14}	21.39	5.5%
17c	Meat	kg/yr	1.30×10^{04}	3.00×10^{13}	0.04	<0.1%
17d	Milk, cheese and other derivatives	kg/yr	2.80×10^{06}	1.44×10^{13}	4.04	1.0%
17e	Fruits and vegetables	kg/yr	4.72×10^{05}	1.01×10^{12}	0.05	<0.1%
17f	Wine and alcoholics	kg/yr	9.23×10^{03}	1.41×10^{12}	0.00	<0.1%
17g	Coffee	kg/yr	0.00×10^{00}	6.10×10^{11}	0.00	0.0%
17h	Sugar	kg/yr	0.00×10^{00}	2.98×10^{12}	0.00	0.0%
18	Metals (Total)	kg/yr	--	--	0.76	0.2%
18a	Aluminum	kg/yr	9.01×10^{03}	7.76×10^{11}	0.00	<0.1%
18b	Cooper	kg/yr	3.13×10^{04}	3.36×10^{12}	0.01	<0.1%
18c	Steel and Iron	kg/yr	1.76×10^{06}	3.16×10^{12}	0.56	0.1%
18d	Gold	kg/yr	0.00×10^{00}	1.50×10^{16}	0.00	0.0%
18e	Other Metals	kg/yr	1.22×10^{06}	1.54×10^{12}	0.19	<0.1%
19	Chemicals	kg/yr	1.94×10^{06}	6.38×10^{11}	0.12	<0.1%
20	Cement	kg/yr	1.22×10^{05}	2.20×10^{12}	0.03	<0.1%
21	Rocks	kg/yr	0.00×10^{00}	1.64×10^{09}	0.00	0.0%
22	Paper and derivatives	kg/yr	5.32×10^{04}	6.55×10^{12}	0.03	<0.1%
23	Plastic	kg/yr	1.02×10^{06}	9.68×10^{12}	0.99	0.3%
24	Textiles	kg/yr	2.62×10^{04}	1.34×10^{14}	0.35	0.1%
25	Glass	kg/yr	4.22×10^{05}	3.50×10^{12}	0.15	<0.1%
26	Machinery	kg/yr	1.13×10^{07}	1.12×10^{13}	12.65	3.2%
27	Wood	kg/yr	1.88×10^{05}	6.79×10^{11}	0.01	<0.1%

28	Cotton	kg/yr	0.00×10^{00}	2.10×10^{13}	0.00	0.0%
29	Services of imports from outside Brazil	USD/yr	2.27×10^{08}	Diverse	138.92	35.6%
	Total of imports from outside Brazil				**179.64**	**46.0%**
	Total of imports					
Exports to outside Brazil						
30	Main food items (Total)	kg/yr	--	--	3.84	
30a	Cereals and derivatives	kg/yr	5.25×10^{05}	6.04×10^{11}	0.03	
30b	Fish	kg/yr	0.00×10^{00}	2.78×10^{14}	0.00	
30c	Meat	kg/yr	0.00×10^{00}	3.00×10^{13}	0.00	
30d	Milk, cheese and other derivatives	kg/yr	2.65×10^{06}	1.44×10^{13}	3.81	
30e	Fruits and vegetables	kg/yr	7.00×10^{00}	1.01×10^{12}	0.00	
30f	Wine and alcoholics	kg/yr	7.92×10^{02}	1.41×10^{12}	0.00	
30g	Coffee	kg/yr	3.90×10^{01}	6.10×10^{11}	0.00	
30h	Sugar	kg/yr	4.00×10^{00}	2.98×10^{12}	0.00	
31	Metals (Total)	kg/yr	--	--	1.37	
31a	Aluminum	kg/yr	2.04×10^{04}	7.76×10^{11}	0.00	
31b	Cooper	kg/yr	1.01×10^{02}	3.36×10^{12}	0.00	
31c	Steel and Iron	kg/yr	1.78×10^{06}	3.16×10^{12}	0.56	
31d	Gold	kg/yr	0.00×10^{00}	1.50×10^{16}	0.00	
31e	Other Metals	kg/yr	5.26×10^{06}	1.54×10^{12}	0.81	
32	Chemicals	kg/yr	1.80×10^{06}	6.38×10^{11}	0.12	
33	Cement	kg/yr	4.16×10^{05}	2.20×10^{12}	0.09	
34	Rocks	kg/yr	1.20×10^{05}	1.64×10^{09}	0.00	
35	Paper and derivatives	kg/yr	1.62×10^{04}	6.55×10^{12}	0.01	
36	Plastic	kg/yr	7.56×10^{06}	9.68×10^{12}	7.32	
37	Textiles	kg/yr	5.94×10^{04}	1.34×10^{14}	0.80	
38	Glass	kg/yr	2.39×10^{05}	3.50×10^{12}	0.08	
39	Machinery	kg/yr	4.96×10^{07}	1.12×10^{13}	55.55	
40	Wood	kg/yr	1.87×10^{06}	6.79×10^{11}	0.13	
41	Cotton	kg/yr	2.20×10^{01}	2.10×10^{13}	0.00	
42	Services of exports to outside Brazil	USD/yr	4.40×10^{08}	8.75×10^{11}	38.50	
	Total of exports to outside Brazil with services				**107.80**	
	Total of exports to outside Brazil without services				**69.31**	
Exports to inside Brazil						
43	Exports of industry to inside Brazil	USD/yr	6.49×10^{08}	8.75×10^{11}	56.78	
44	Exports of services to inside Brazil	USD/yr	4.53×10^{07}	8.75×10^{11}	3.96	
45	Labor	people/yr	3.25×10^{04}	2.12×10^{16}	68.81	
	Total of exports to inside Brazil				**129.56**	
	Total of exports (internal+external) with services				**237.36**	
	Total of exports (internal+external) without services				**198.86**	
	Total Emergy				**390.39**	

(*) Rain was calculated as the sum of items 2 and the greatest value between items 3 or 4

(**) The total of renewable resources was calculated comparing the emergy value accounted for rain (explained above) with the sum of items 1 and 6. The greatest value between these two values was considered the total of renewable resources.

Detailed calculations are available in Appendix C.

Table B4 – Matter, energy and emergy flows supporting ABC Paulista.

	Item	Units	Quantity	UEV (sej/unit)	Emergy x 10^{19} (sej/year)	Percentage of the total emergy
Local renewable resources						
1	Solar radiation	J/yr	2.63×10^{18}	1	0.26	<0.1%
2	Rain (Chem. energy in green areas) (*)	J/yr	3.10×10^{15}	3.10×10^{04}	9.63	0.2%
3	Rain (Chem. energy of run-off) (*)	J/yr	1.06×10^{13}	3.10×10^{04}	0.03	<0.1%
4	Rain (Geopotential energy) (*)	J/yr	4.35×10^{14}	4.70×10^{04}	2.04	<0.1%
5	Kinetic wind energy	J/yr	1.14×10^{15}	2.45×10^{03}	0.28	<0.1%
6	Geothermal heat	J/yr	1.01×10^{15}	5.80×10^{04}	5.89	0.1%
7	Water use from Billings dam	m^3/yr	9.66×10^{07}	3.81×10^{11}	3.69	0.1%
8	Evaporation	m^3/yr	1.45×10^{07}	2.44×10^{11}	0.35	<0.1%
	Total of renewable resources (**)					
Local non-renewable resources						
	Topsoil loss	J/yr	6.62×10^{07}	1.24×10^{05}	0.00	<0.1%
	Total of non-renewable resources				**0.00**	**<0.1%**
Imports from inside Brazil						
10	Fuels (Total)	J/yr	--	--	349.84	8.5%
10a	Natural gas	J/yr	1.63×10^{16}	6.84×10^{04}	111.47	2.7%
10b	Gasoline	J/yr	1.11×10^{16}	1.11×10^{05}	122.90	3.0%
10c	Diesel	J/yr	8.16×10^{15}	1.11×10^{05}	90.45	2.2%
10d	Sugarcane Ethanol	J/yr	5.14×10^{15}	4.87×10^{04}	25.01	0.6%
11	Electricity (Total)	J/yr	2.18×10^{16}	2.77×10^{05}	603.35	14.7%
11a	Residential	J/yr	4.83×10^{15}	2.77×10^{05}	133.95	3.3%
11b	Commercial	J/yr	2.83×10^{15}	2.77×10^{05}	78.48	1.9%
11c	Industrial	J/yr	1.37×10^{16}	2.77×10^{05}	379.33	9.2%
11d	Public Lighting	J/yr	4.18×10^{14}	2.77×10^{05}	11.58	0.3%
12	Treated water	L/yr	9.81×10^{10}	1.55×10^{09}	15.21	0.4%
13	Food	J/yr	7.50×10^{15}	1.43×10^{05}	107.11	2.6%
14	Services from inside Brazil	USD/yr	2.79×10^{08}	4.78×10^{12}	133.15	3.2%
15	Agriculture goods from inside Brazil	USD/yr	6.94×10^{08}	4.78×10^{12}	331.30	8.1%
16	Labor	kg/yr	2.77×10^{05}	2.04×10^{16}	564.56	13.7%
	Total of Imports from inside Brazil (F_{int}) with services				**2,104.51**	**51.2%**
	Total of Imports from inside Brazil (F_{int}) without services				**1,971.37**	
Imports from outside Brazil						
17	Main food items (Total)	kg/yr	--	--	92.09	2.2%
17a	Cereals and derivatives	kg/yr	5.44×10^{06}	6.04×10^{11}	0.33	0.0%
17b	Fish	kg/yr	2.96×10^{06}	2.78×10^{14}	82.27	2.0%
17c	Meat	kg/yr	4.54×10^{04}	3.00×10^{13}	0.14	0.0%
17d	Milk, cheese and other derivatives	kg/yr	6.02×10^{06}	1.44×10^{13}	8.67	0.2%
17e	Fruits and vegetables	kg/yr	4.72×10^{06}	1.01×10^{12}	0.48	0.0%
17f	Wine and alcoholics	kg/yr	1.07×10^{06}	1.41×10^{12}	0.15	0.0%
17g	Coffee	kg/yr	6.80×10^{05}	6.10×10^{11}	0.04	0.0%
17h	Sugar	kg/yr	6.03×10^{04}	2.98×10^{12}	0.02	0.0%
18	Metals (Total)	kg/yr	--	--	51.66	1.3%
18a	Aluminum	kg/yr	1.40×10^{06}	7.76×10^{11}	0.11	0.0%
18b	Cooper	kg/yr	3.25×10^{06}	3.36×10^{12}	1.09	0.0%
18c	Steel and Iron	kg/yr	2.41×10^{07}	3.16×10^{12}	7.62	0.2%
18d	Gold	kg/yr	2.65×10^{04}	1.50×10^{16}	39.82	1.0%
18e	Other Metals	kg/yr	1.96×10^{07}	1.54×10^{12}	3.02	0.1%
19	Chemicals	kg/yr	2.43×10^{08}	6.38×10^{11}	15.54	0.4%
20	Cement	kg/yr	1.26×10^{06}	2.20×10^{12}	0.28	0.0%
21	Rocks	kg/yr	2.40×10^{06}	1.64×10^{09}	0.00	0.0%
22	Paper and derivatives	kg/yr	1.84×10^{07}	6.55×10^{12}	12.07	0.3%
23	Plastic	kg/yr	8.73×10^{07}	9.68×10^{12}	84.46	2.1%
24	Textiles	kg/yr	4.66×10^{06}	1.34×10^{14}	62.46	1.5%
25	Glass	kg/yr	3.49×10^{06}	3.50×10^{12}	1.22	0.0%
26	Machinery	kg/yr	1.20×10^{08}	1.12×10^{13}	133.95	3.3%
27	Wood	kg/yr	9.10×10^{05}	6.79×10^{11}	0.06	0.0%

28	Cotton	kg/yr	1.68×10^{05}	2.10×10^{13}	0.35	0.0%
29	Services of imports from outside Brazil	USD/yr	2.84×10^{09}	Diverse	1,542.85	37.5%
	Total of imports from outside Brazil (F_{ext}) with services				**1,997.00**	**48.6%**
	Total of imports from outside Brazil (F_{ext}) without services				**454.15**	
	Total of imports (internal+external) with services				**4,101.51**	
	Total of imports (internal+external) without services				**2,425.51**	
Exports to outside Brazil						
30	Main food items (Total)	kg/yr	--	--	7.64	
30a	Cereals and derivatives	kg/yr	4.87×10^{02}	6.04×10^{11}	2.23	
30b	Fish	kg/yr	4.86×10^{05}	2.78×10^{14}	0.01	
30c	Meat	kg/yr	2.65×10^{06}	3.00×10^{13}	1.46	
30d	Milk, cheese and other derivatives	kg/yr	1.19×10^{05}	1.44×10^{13}	3.81	
30e	Fruits and vegetables	kg/yr	2.66×10^{05}	1.01×10^{12}	0.01	
30f	Wine and alcoholics	kg/yr	1.01×10^{04}	1.41×10^{12}	0.04	
30g	Coffee	kg/yr	2.58×10^{05}	6.10×10^{11}	0.00	
30h	Sugar	kg/yr	4.87×10^{02}	2.98×10^{12}	0.08	
31	Metals (Total)	kg/yr	--	--	15.22	
31a	Aluminum	kg/yr	3.80×10^{06}	7.76×10^{11}	0.30	
31b	Cooper	kg/yr	1.21×10^{07}	3.36×10^{12}	4.07	
31c	Steel and Iron	kg/yr	7.25×10^{06}	3.16×10^{12}	2.29	
31d	Gold	kg/yr	3.23×10^{03}	1.50×10^{16}	4.85	
31e	Other Metals	kg/yr	2.41×10^{07}	1.54×10^{12}	3.71	
32	Chemicals	kg/yr	1.72×10^{08}	6.38×10^{11}	10.96	
33	Cement	kg/yr	2.61×10^{06}	2.20×10^{12}	0.57	
34	Rocks	kg/yr	3.36×10^{05}	1.64×10^{09}	0.00	
35	Paper and derivatives	kg/yr	1.00×10^{06}	6.55×10^{12}	0.66	
36	Plastic	kg/yr	2.00×10^{08}	9.68×10^{12}	193.18	
37	Textiles	kg/yr	1.19×10^{07}	1.34×10^{14}	159.28	
38	Glass	kg/yr	8.25×10^{06}	3.50×10^{12}	2.89	
39	Machinery	kg/yr	2.73×10^{08}	1.12×10^{13}	306.06	
40	Wood	kg/yr	1.23×10^{07}	6.79×10^{11}	0.83	
41	Cotton	kg/yr	3.28×10^{02}	2.10×10^{13}	0.00	
42	Services of exports to outside Brazil	USD/yr	3.97×10^{09}	1.56×10^{12}	620.95	
	Total of exports to outside Brazil with services				**1,318.23**	
	Total of exports to outside Brazil without services				**697.28**	
Exports to inside Brazil						
43	Exports of industry to inside Brazil	USD/yr	4.87×10^{09}	1.56×10^{12}	761.80	
44	Exports of services to inside Brazil	USD/yr	0.00×10^{00}	1.56×10^{12}	0.00	
45	Labor	people/yr	2.67×10^{05}	2.59×10^{16}	692.30	
	Total of exports to inside Brazil				**1,454.10**	
	Total of exports (internal+external) with services				**2,772.33**	
	Total of exports (internal+external) without services				**2,151.38**	
	Total Emergy				**4,113.18**	

(*) Rain was calculated as the sum of items 2 and the greatest value between items 3 or 4

(**) The total of renewable resources was calculated comparing the emergy value accounted for rain (explained above) with the sum of items 1 and 6. The greatest value between these two values was considered the total of renewable resources.

Complete tables and detailed calculations are available in Appendix B and C.

Appendix C

The calculations below are detailed for Santo André municipality. Some of the calculations are detailed for the other municipalities as well. The calculations for São Bernardo do Campo and São Caetano do Sul used the same procedures and the same methods.

Local renewable resources

1- Solar Energy

Continental Shelf Area = 0 m^2

Land Area = 1.75 x 10^{08} m^2 (IBGE 2009)

Insolation = 1.32 x 10^{02} kcal/cm^2/yr (CRESESB 2009)

Albedo = 20% or 0.2 (CERES/SARB 2009)

Energy = (Area incl. shelf)*(avg. insolation)*(1-albedo)

Energy = (____m^2)*(____kcal/cm^2/yr)*(x $10^{04}$$cm^2$/$m^2$)*(1-albedo)*(4,186J/kcal)

Energy = 7.73 x 10^{17} J/yr

2- Rain, chemical potential energy in green area

Land Area = 1.75 x 10^{08} m^2 (IBGE 2009)

Rain (land) = 3.10 m/yr (sigrh.sp.gov.br)

% of green area = 35.78%

Rain in green area = (total rain)*(% of green area)

Rain in green area = 1.11 m/yr

Evapotranspired rain = 0.89 m/yr (est. as 80% of total rain in green area) (Kohler et al., 1959)

Energy = (area)*(evapotranspired rain)*(Gibbs free energy)

Energy = (____m^2)*(____m)*(1,000kg/m^3)*(4.94E3J/kg)

Energy = 7.67 x 10^{14} J/yr

3- Rain, chemical potential energy run-off

Land Area = 1.75 x 10^{08} m^2 (IBGE 2009)

Rain (land) = 3.10 m/yr (sigrh.sp.gov.br)

% of urban area = 64.22%

Rain in urban area = (total rain)*(% of urban area)

Rain in urban area = 1.99 m/yr

Run-off rain = 1.59 m/yr (est. as 80% of total rain in urban area) (estimated)

Energy = (area)*(run-off rain)*(Gibbs free energy) Gibbs free energy considering rain 10ppm and run-off 100ppm

Energy = (____m^2)*(____m)*(1,000kg/m^3)*(12.5J/kg)

Energy = 3.48 x 10^{12} J/yr

4- Rain, geopotential energy

Land Area = 1.75 x 10^{08} m^2 (IBGE 2009)

Rain (land) = 3.10 m/yr (sigrh.sp.gov.br)

Average elevation = 30.00 m (estimated)

% of green area = 35.78%

% of urban area = 64.22%

Run-off rain = 1.59 m/yr (est. as 80% of total rain in urban area)

Energy = (land area)*(run-off)*(avg. elevation)*(gravity acceleration)

Energy = (____m^2)*(____m)*(____%)*(1000kg/m^3)*(___m)*(9.8m/s^2)

Energy = 8.19 x 10^{13} J/yr

5- Wind energy

Land Area = 1.75 x 10^{08} m^2 (IBGE 2009)

Density of the air = 1.30 kg/m^3 (Odum, 1996)

Average annual wind velocity = 3.60 m/s (windfinder.com)

Drag coefficient = 1.00 x 10^{-3} (Miller, 1964 quoted by Kraus, 1972)

Energy = (land area)*(air density)*(drag coefficient)*($velocity^3$)

Energy = (_____m^2)*(1.30 kg/m^3)*(1.00 x 10^{-3})*(______$(m/s)^3$)*(3.14 x 10^{07} s/yr)

Energy = 3.33 x 10^{14} J/yr

6- Earth cycle (deep heat)

Land Area = 1.75 x 10^{08} m^2 (IBGE 2009)

Heat flow = 5.40 x 10^{01} mW/m^2 (Gomes and Hamza, 2004)

Heat flow = 1.70 x 10^{06} J/yr/m^2 (unit transformation)

Energy = (land area)*(heat flow)

Energy = (____m^2)*(____J/yr/m^2)

Energy = 2.98 x 10^{14} J/yr

7- Water use from Billings dam

Total area of the dam = 1.27 x 10^{08} m^2 (Rocca, 1995)

Total volume of the dam = 1.15 x 10^{09} m^3 (Rocca, 1995)

Area of the dam inside the municipality = 1.27 x 10^{08} m^2

Percentage of the dam inside the municipality = 5.40 %

Volume of the dam inside the municipality = 6.21 x 10^{07} m^3

Density of water = 1.00 x 10^{03} kg/m^3

Mass of water inside the municipality = 6.21 x 10^{10} kg

Pumped flow = 4.70 m^3/s (Rocca, 1995)

Flow = (4.70m^3/s)*(86,400s/day)*(365days)*(% of the dam inside municipality)

Flow = 8.01 x 10^{06} m^3/yr

8- Evaporation (water dam)

Total Evaporation Billings Dam = 2.69 x 10^{02} mm/yr (ONS – Op. Nac. do Sist. Elétrico)

Percentage of the dam inside the municipality = 5.40 %

Evaporation inside municipality = 1.45 x 10^{01} mm/yr

Volume evaporated inside municipality = (total evaporation)*(% of the dam inside municipality)*(area of the dam inside municipality)

Volume evaporated inside municipality = (_____mm/yr)*(1m/1,000mm)*(_____%)*(______m^2)

Volume evaporated inside municipality = 9.96 x 10^{04} m^3/yr

Density of water = 1.00 x 10^{03} kg/m^3

Mass evaporated inside municipality = (volume evaporated inside municipality)*(density of water)

Mass evaporated inside municipality = (_____m^3/yr)*(1,000kg/m^3)

Mass evaporated inside municipality = 9.96 x 10^{07} kg/yr

Local non-renewable resources

9- Topsoil loss

Farmed Area = 2.40 x 10^{05} m^2

Erosion Rate of Farmed Area = g/m^2/yr (Ascione et al., 2009)

Net loss = (farmed area)*(erosion rate)

Net loss = (_____m^2)*(______g/m^2/yr)

Net loss = 3.60 x 10^{08} g/yr

%organic in soil = 3.00% (estimated)

Embodied organic energy/g = 5.00 kcal/g

Energy = (net loss)*(%organic in soil)*(5kcal/g)*(4,186J/kcal)

Energy = 2.26 x 10^{11} J/yr

Imports from inside Brazil

10- Fuels

10a – Natural gas

Natural gas consumption = 3.10 x 10^{08} m^3/yr (SEADE, 2012)

Energy = (____ m^3/yr)*(8,800 kcal/m^3)*(4,186 J/kcal)

Energy = 1.14 x 10^{16} J/yr

10b – Gasoline

Gasoline consumption = 1.41 x 10^{08} L/yr (SEADE, 2012)

Energy = (____ L/yr)*(7844.2 kcal/L)*(4,186 J/kcal)

Energy = 4.63 x 10^{15} J/yr

10c – Diesel

Diesel consumption = 6.20 x 10^{07} L/yr (SEADE, 2012)

Energy = (____ L/yr)*(8,605.2 kcal/L)*(4,186 J/kcal)

Energy = 2.23 x 10^{15} J/yr

10d – Ethanol

Ethanol consumption = 1.01 x 10^{08} L/yr (SEADE, 2012)

Energy = (____ L/yr)*(5,096.7 kcal/L)*(4186 J/kcal)

Energy = 2.15 x 10^{15} J/yr

11- Electricity

11a, 11b, 11c, 11d correspond to different uses of electricity. Residential, commercial, industrial and public lighting. All the different uses are calculated in the same way.

Electricity consumption = 2.77 x 10^{09} kWh/yr (SEADE, 2012)

Energy = (____ kWh/yr)*(3.60 J/kWh)

Energy = 9.97 x 10^{15} J/yr

12- Water

Water consumption = 4.14 x 10^{10} L/yr (SNIS 2013)

13- Food for population

Calculation based on a diary consumption of 3000 kcal/day.

Energy = (3,000 kcal/day)*(4,186 J/kcal)*(365 days/yr)*(___inhabit.)

Energy = 3.09 x 10^{15} J/yr

14- Services from inside Brazil

Calculated using the Shif-share analysis procedures.

Santo André

LQ_i = 0.936 (Imports) X_i = -13,100.38 (minus indicate imports)

USD/worker = 15,831.57 USD/worker (from Brazil)

Amount imported = -2.07 x 10^{08}USD

EMR of Brazil = 4.78 x 10^{12} sej/USD

Emergy = (amount imported)*(EMR of Brazil)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = -9.90 x 10^{20} sej

São Bernardo do Campo

LQ_i = 0.975 (Imports) X_i = -5,703.34 (minus indicate imports)

USD/worker = 15,831.57 USD/worker (from Brazil)

Amount imported = -9.03 x 10^{07} USD

EMR of Brazil = 4.78 x 10^{12} sej/USD

Emergy = (amount imported)*(EMR of Brazil)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = -4.31 x 10^{20} sej

São Caetano do Sul

LQ_i = 1.025 (Exports)

Value imported = zero

Energy = zero

ABC Paulista as a whole

LQ_i = 0.963 (Imports) X_i = -17,610.66 (minus indicate imports)

USD/worker = 15,831.57 USD/worker (from Brazil)

Amount imported = -2.79 x 10^{08} USD

EMR of Brazil = 4.78 x 10^{12} sej/USD

Emergy = (amount imported)*(EMR of Brazil)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = -1.33 x 10^{21} sej

15- Agriculture goods from inside Brazil

Calculated using the Shif-share analysis procedures.

Santo André

LQ_i = 0.017 (Imports) X_i = -55,974.01 (minus indicate imports)

USD/worker = 5,276.92 USD/worker (from Brazil)

Amount imported = -2.95 x 10^{08} USD

EMR of Brazil = 4.78 x 10^{12} sej/USD

Emergy = (amount imported)*(EMR of Brazil)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = -1.41 x 10^{21} sej

São Bernardo do Campo

LQi = 0.031 (Imports) Xi = -62,473.20 (minus indicate imports)

USD/worker = 5,276.92 USD/worker (from Brazil)

Amount imported = -3.30 x 10^{08} USD

EMR of Brazil = 4.78 x 10^{12} sej/USD

Emergy = (amount imported)*(EMR of Brazil)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = -1.57 x 10^{21} sej

São Caetano do Sul

LQ_i = 0.016 (Imports) X_i = -13,019.72

USD/worker = 5,276.92 USD/worker (from Brazil)

Amount imported = -6.87 x 10^{07} USD

EMR of Brazil = 4.78 x 10^{12} sej/USD

Emergy = (amount imported)*(EMR of Brazil)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = -3.28 x 10^{20} sej

ABC Paulista as a whole

LQ_i = 0.024 (Imports) X_i = -131,466.93

USD/worker = 5276.92 USD/worker (from Brazil)

Amount imported = -6.94 x 10^{08} USD

EMR of Brazil = 4.78 x 10^{12} sej/USD

Emergy = (amount imported)*(EMR of Brazil)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = -3.31 x 10^{21} sej

16- Labor

The calculation of workers exchange can be found in Appendix G.

Imported workers = 1.28 x 10^{05} people/yr (IBGE, 2013)

Considering that the worker is a commuter that works during the year in the given municipality.

Emergy = (imported workers)*(emergy/capita of the worker of SP state sej/cap) (Demétrio, 2011)

Emergy = (____ people/yr)*(2.04 x 10^{16} sej/cap)

Emergy = 2.62 x 10^{21} sej/yr

Imports from outside Brazil

17- Main food items

17a- Cereals and derivatives

Amount imported = 5.04 x 10^{05} kg/yr (SECEX, 2012)

17b- Fish

Amount imported = 1.59 x 10^{04} kg/yr (SECEX, 2012)

17c- Meat

Amount imported = 1.62 x 10^{04} kg/yr (SECEX, 2012)

17d- Milk, cheese and other derivatives

Amount imported = 4.14 x 10^{05} kg/yr (SECEX, 2012)

17e- Fruits and vegetables

Amount imported = 4.29 x 10^{05} kg/yr (SECEX, 2012)

17f- Wine and alcoholics (imported by other municipalities)

Amount imported = 0.00 x 10^{00}kg/yr (SECEX, 2012)

17g- Coffee (imported by other municipalities)

Amount imported = 0.00 x 10^{00}kg/yr (SECEX, 2012)

17h- Sugar (imported by other municipalities)

Amount imported = 0.00 x 10^{00}kg/yr (SECEX, 2012)

18- Metals

18a- Aluminum

Amount imported = 1.16 x 10^{06} kg/yr (SECEX, 2012)

18b- Cooper

Amount imported = 8.30 x 10^{05} kg/yr (SECEX, 2012)

18c- Steel and Iron

Amount imported = 4.61 x 10^{06} kg/yr (SECEX, 2012)

18d- Gold

Amount imported = 1.12 x 10^{03} kg/yr (SECEX, 2012)

18e- Other metals

Amount imported = 8.41 x 10^{05} kg/yr (SECEX, 2012)

19- Chemicals

Amount imported = 1.92 x 10^{08} kg/yr (SECEX, 2012)

20- Cement

Amount imported = 6.40 x 10^{05} kg/yr (SECEX, 2012)

21- Rocks

Amount imported = 1.35 x 10^{06} kg/yr (SECEX, 2012)

22- Paper and derivatives

Amount imported = 6.42 x 10^{06} kg/yr (SECEX, 2012)

23- Plastic

Amount imported = 5.49 x 10^{07} kg/yr (SECEX, 2012)

24- Textiles

Amount imported = 1.67 x 10^{06} kg/yr (SECEX, 2012)

25- Glass

Amount imported = 3.62 x 10^{03} kg/yr (SECEX, 2012)

26- Machinery

Amount imported = 5.89 x 10^{06} kg/yr (SECEX, 2012)

27- Wood

Amount imported = 2.43 x 10^{04} kg/yr (SECEX, 2012)

28- Cotton (imported by other municipalities)

Amount imported = 0.00 x 10^{00} kg/yr (SECEX, 2012)

29- Services of imports from outside Brazil

The amount imported refers to the value of imports from outside Brazil in the year 2009 according to SECEX.

Amount imported = 4.54 x 10^{08} USD/yr

The EMR used to calculate the emergy of services embodied in the imports was the one for each country from where the product was imported (NEAD, 2012). This procedure was made for the 40 most valuable imports. The rest were calculated using weighted average of all the imports for this municipality.

Exports to outside Brazil

30- Main food items

30a- Cereals and derivatives

Amount exported = 9.25 x 10^{03} kg/yr (SECEX, 2012)

30b- Fish

Amount exported = 4.87 x 10^{02} kg/yr (SECEX, 2012)

30c- Meat

Amount exported = 0.00 x 10^{00} kg/yr (SECEX, 2012)

30d- Milk, cheese and other derivatives

Amount exported = 4.20 x 10^{01} kg/yr (SECEX, 2012)

30e- Fruits and vegetables

Amount exported = 1.13 x 10^{04} kg/yr (SECEX, 2012)

30f- Wine and alcoholics (imported by other municipalities)

Amount exported = 1.37 x 10^{03}kg/yr (SECEX, 2012)

30g- Coffee

Amount exported = 7.79 x 10^{03}kg/yr (SECEX, 2012)

30h- Sugar

Amount exported = 2.44 x 10^{05}kg/yr (SECEX, 2012)

31- Metals

31a- Aluminum

Amount exported = 2.37 x 10^{06} kg/yr (SECEX, 2012)

31b- Cooper

Amount exported = 1.08 x 10^{07} kg/yr (SECEX, 2012)

31c- Steel and Iron

Amount exported = 9.63 x 10^{05} kg/yr (SECEX, 2012)

31d- Gold

Amount exported = 3.14 x 10^{03} kg/yr (SECEX, 2012)

31e- Other metals

Amount exported = 0.00 x 10^{00} kg/yr (SECEX, 2012)

32- Chemicals

Amount exported = 1.02 x 10^{08} kg/yr (SECEX, 2012)

33- Cement

Amount exported = 4.03 x 10^{03} kg/yr (SECEX, 2012)

34- Rocks

Amount exported = 8.00 x 10^{03} kg/yr (SECEX, 2012)

35- Paper and derivatives

Amount exported = 1.67 x 10^{03} kg/yr (SECEX, 2012)

36- Plastic

Amount exported = 1.56 x 10^{08} kg/yr (SECEX, 2012)

37- Textiles

Amount exported = 1.11 x 10^{07} kg/yr (SECEX, 2012)

38- Glass

Amount exported = 1.67 x 10^{03} kg/yr (SECEX, 2012)

39- Machinery

Amount exported = 3.84 x 10^{06} kg/yr (SECEX, 2012)

40- Wood

Amount exported = 4.50 x 10^{02} kg/yr (SECEX, 2012)

41- Cotton

Amount exported = 9.60 x 10^{01} kg/yr (SECEX, 2012)

42- Services of exports to outside Brazil

The amount exported refers to the value of exports from the municipality to the rest of the world in the year 2009 according to SECEX (2012).

Amount exported = 6.35 x 10^{08} USD/yr

The EMR used to calculate the emergy of services embodied in the exports was the one for each municipality from where the product was exported.

Exports to inside Brazil

43- Industry goods to inside Brazil

Calculated using the Shif-share analysis procedures.

Santo André

LQ_i = 1.933 (Exports) X_i = 69,074.39

USD/worker = 23,674.44 USD/worker (from Santo André)

Amount exported = 1.64 x 10^{09} USD

EMR of Santo André = 1.98 x 10^{12} sej/USD

Emergy = (amount exported)*(EMR of Santo André)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = 3.24 x 10^{21} sej

São Bernardo do Campo

LQ_i = 1.813 (Exports) X_i = 68,176.54

USD/worker = 34,432.44 USD/worker (from Brazil)

Amount exported = 2.35 x 10^{09} USD

EMR of São Bernardo do Campo = 1.58 x 10^{12} sej/USD

Emergy = (amount exported)*(EMR of São Bernardo do Campo)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = 3.70 x 10^{21} sej

São Caetano do Sul

LQ_i = 1.688 (Exports) X_i = 11,826.66

USD/worker = 54,849.60 USD/worker (from São Caetano do Sul)

Amount exported = 6.49 x 10^{08} USD

EMR of São Caetano do Sul = 8.75 x 10^{11} sej/USD

Emergy = (amount exported)*(EMR of São Caetano do Sul)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = 5.68 x 10^{20} sej

ABC Paulista as a whole

LQ_i = 1.852 (Exports) X_i = 149,077.59

USD/worker = 32,652.84 USD/worker (from ABC)

Amount exported = 4.87 x 10^{09} USD

EMR of ABC = 1.56 x 10^{12} sej/USD

Emergy = (amount exported)*(EMR of ABC)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = 7.62 x 10^{21} sej

44- Services to inside Brazil

Calculated using the Shif-share analysis procedures.

Santo André

LQ_i = 0.936 (Imports) X_i = -13,100.38 (minus indicate imports)

Value exported = zero

Energy = zero

São Bernardo do Campo

LQ_i = 0.975 (Imports) X_i = -5,703.34 (minus indicate imports)

Value exported = zero

Energy = zero

São Caetano do Sul

LQ_i = 1.025 (Exports) X_i = 1,193.06

USD/worker = 37,960.92 USD/worker (from São Caetano do Sul)

Amount exported = 4.53 x 10^{07} USD

EMR of São Caetano do Sul = 8.75 x 10^{11} sej/USD

Emergy = (amount exported)*(EMR of São Caetano do Sul)

Emergy = (________ USD)*(_________ sej/USD)

Emergy = 3.96 x 10^{19} sej

ABC Paulista as a whole

LQ_i = 0.963 (Imports) X_i = -17,610.66 (minus indicate imports)

Value exported = zero

Energy = zero

45- Labor

The calculation of workers exchange can be found in Appendix G.

Exported workers = 1.25 x 10^{05} people/yr (IBGE, 2013)

Considering that the worker is a commuter that works out of the municipality during the year.

Emergy = (exported workers)*(emergy/capita of the worker of Santo André sej/cap)

Emergy = (____ people/yr)*(1.92 x 10^{16} sej/cap)

Emergy = 2.39 x 10^{21} sej/yr

Appendix D

The tables below show the results of the calculation of Shift-Share analysis for Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

The value of amount exported or imported is the money related to exports or imports between each municipality and the rest of Brazil. The exports or imports between each municipality and the rest of the world are not included in these tables and neither were calculated using this method.

Table D1 – Employee values for Santo André, São Bernardo do Campo, São Caetano do Sul, ABC and Brazil.

Economic activity	Santo André		São Bernardo do Campo		São Caetano do Sul		ABC		Brazil	
	Percentage of workers	Total of workers (*)	Percentage of workers	Total of workers (*)	Percentage of workers	Total of workers (*)	Percentage of workers	Total of workers (*)	Percentage of workers	Total of workers (*)
Industry	37.41%	1.25×10^{05}	34.97%	1.33×10^{05}	33.71%	2.62×10^{04}	35.88%	2.84×10^{05}	14.70%	1.5×10^{07}
Construction	5.31%	1.78×10^{04}	5.11%	1.94×10^{04}	3.59%	2.79×10^{03}	5.04%	4.00×10^{04}	7.40%	7.5×10^{06}
Industry + Construction	**42.72%**	**1.43×10^{05}**	**45.38%**	**1.52×10^{05}**	**8.67%**	**2.90×10^{04}**	**40.92%**	**3.24×10^{05}**	**22.10%**	**2.2×10^{07}**
Commerce	18.25%	6.11×10^{04}	21.08%	7.99×10^{04}	19.99%	1.56×10^{04}	19.77%	1.57×10^{05}	--	--
Services	38.74%	1.30×10^{05}	38.32%	1.45×10^{05}	42.44%	3.30×10^{04}	38.90%	3.08×10^{05}	--	--
Services + Commerce	**56.99%**	**1.91×10^{05}**	**67.25%**	**2.25×10^{05}**	**14.50%**	**4.86×10^{04}**	**58.68%**	**4.65×10^{05}**	**60.90%**	**6.2×10^{07}**
Agriculture and livestock	**0.29%**	**9.68×10^{02}**	**0.53%**	**2.00×10^{03}**	**0.27%**	**2.09×10^{02}**	**0.40%**	**3.18×10^{03}**	**17.00%**	**1.7×10^{07}**
Economic Active Population	3.35×10^{05}		3.79×10^{05}		7.78×10^{04}		7.92×10^{05}		1.0×10^{08}	

(*) Values from IBGE (2012 and 2013).

The values of e_i/e and E_i/E shown in Table D2 were calculated using the data of employment shown at Table D1.

Table D2 – Shift-share analysis results for Santo André, São Bernardo do Campo, São Caetano do Sul and for ABC as a whole.

Industry/sector	e_i/e	LQ_i	X_i	Conclusions	USD/worker	Amount exported or imported (USD)
Santo André (SA)						
Industry (incl. construction)	0.427	1.933	69,074.39	Exports(*)	23,674.44	1.64×10^{09}
Services (incl. commerce)	0.570	0.936	-13,100.38	Imports(**)	17,631.26	-2.07×10^{08}
Agriculture and livestock	0.003	0.017	-55,974.01	Imports(**)	7,319.28	-2.95×10^{08}
São Bernardo do Campo (SBC)						
Industry (incl. construction)	0.401	1.813	68,176.54	Exports(*)	34,432.44	2.35×10^{09}
Services (incl. commerce)	0.594	0.975	-5,703.34	Imports(**)	29,003.10	-9.03×10^{07}
Agriculture and livestock	0.005	0.031	-62,473.20	Imports(**)	38,147.76	-3.30×10^{08}
São Caetano do Sul (SCS)						
Industry (incl. construction)	0.373	1.688	11,826.66	Exports(*)	54,849.60	6.49×10^{08}
Services (incl. commerce)	0.624	1.025	1,193.06	Exports(*)	37,960.92	4.53×10^{07}
Agriculture and livestock	0.003	0.016	-13,019.72	Imports(**)	0	-6.87×10^{07}
ABC as a whole						
Industry (incl. construction)	0.409	1.852	149,077.59	Exports(*)	32,652.84	4.87×10^{09}
Services (incl. commerce)	0.587	0.963	-17,610.66	Exports(*)	33,167.57	-2.79×10^{08}
Agriculture and livestock	0.004	0.024	-131466.93	Imports(**)	14,904.85	-6.94×10^{08}

(*) when the municipality exports, the USD/worker relation is the one from the municipality.
(**) when the municipality imports, the USD/worker relation is the one from Brazil shown at Table D3.

Table D3 – E_i/E and USD/worker for Brazil.

Industry	E_i/E	USD/worker
Brazil		
Industry (incl. construction)	0.221	19,426.01
Services (incl. commerce)	0.609	15,831.57
Agriculture and livestock	0.170	5,276.92

Table D4 – EMR of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole and Brazil.

Location	EMR (sej/USD)
Santo André	1.98×10^{12}
São Bernardo do Campo	1.58×10^{12}
São Caetano do Sul	8.75×10^{11}
ABC as a Whole	1.56×10^{12}
Brazil	4.78×10^{12}

Table D5 – Emergy imported or exported by Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

Industry/sector	Conclusions	Amount exported or imported (USD)	Emergy exported or imported (sej)
Santo André (SA)			
Industry (incl. construction)	Exports	1.64×10^{09}	3.24×10^{21}
Services (incl. commerce)	Imports	-2.07×10^{08}	-9.90×10^{20}
Agriculture and livestock	Imports	-2.95×10^{08}	-1.41×10^{21}
São Bernardo do Campo (SBC)			
Industry (incl. construction)	Exports	2.35×10^{09}	3.70×10^{21}
Services (incl. commerce)	Imports	-9.03×10^{07}	-4.31×10^{20}
Agriculture and livestock	Imports	-3.30×10^{08}	-1.57×10^{21}
São Caetano do Sul (SCS)			
Industry (incl. construction)	Exports	6.49×10^{08}	5.68×10^{20}
Services (incl. commerce)	Exports	4.53×10^{07}	3.96×10^{19}
Agriculture and livestock	Imports	-6.87×10^{07}	-3.28×10^{20}
ABC as a whole			
Industry (incl. construction)	Exports	4.87×10^{09}	7.06×10^{21}
Services (incl. commerce)	Exports	-2.79×10^{08}	-1.33×10^{21}
Agriculture and livestock	Imports	-6.94×10^{08}	-3.31×10^{21}

Appendix E

In this appendix are shown calculations and tables for the stocks of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

Building stock estimate calculation

The resources used in a standard medium construction were obtained from Demétrio (2012). The resources calculations are shown in Table E1.

Table E1 – Calculation of the emergy per area of a standard medium construction.

Resources	Quantity	Unit/m^2	UEV (sej/unit)	Reference for UEV	Emergy	%
Wood	1.52×10^{01}	kg	2.40×10^{12}	a	3.65×10^{13}	0.75%
Steel/Iron	7.02×10^{01}	kg	6.97×10^{12}	b	4.89×10^{14}	10.07%
Cooper	3.47×10^{-01}	kg	1.04×10^{14}	c	3.61×10^{13}	0.74%
Sand	5.78×10^{02}	kg	1.68×10^{12}	a	9.71×10^{14}	19.98%
Ceramic Masonry	3.81×10^{02}	kg	3.68×10^{12}	b	1.40×10^{15}	28.86%
China	5.66×10^{01}	kg	4.80×10^{12}	b	2.72×10^{14}	5.59%
Cement	1.73×10^{02}	kg	3.04×10^{12}	d	5.26×10^{14}	10.82%
Glass	1.37×10^{00}	kg	1.41×10^{12}	a	1.93×10^{12}	0.04%
Plaster	1.34×10^{02}	kg	3.29×10^{12}	c	4.41×10^{14}	9.07%
Granite	2.33×10^{02}	kg	2.44×10^{12}	c	5.69×10^{14}	11.70%
Asphalt	1.23×10^{00}	kg	2.55×10^{13}	b	3.14×10^{13}	0.65%
PVC tubes	4.48×10^{-02}	kg	9.86×10^{12}	b	4.42×10^{11}	0.01%
Paint	3.24×10^{00}	kg	2.55×10^{13}	b	8.26×10^{13}	1.70%
Water	6.80×10^{02}	kg	9.23×10^{08}	e	6.28×10^{11}	0.01%
				Emergy/m^2	4.86×10^{15}	sej/m^2

Adapted from Demétrio (2012).
References for transformity used by Demétrio (2012): a- Odum, 1996; b- Brown and Buranakarn, 2000; c- Pulselli et al., 2007c; d- Pulselli et al., 2007b; e- Buenfil, 2001; planetary baseline of 15.83×10^{24} sej/year (Odum et al., 2000).

The estimate of areas by different use was made by observation of maps found at the city council websites resulting the data shown in Table E2.

Table E2 – Estimate of areas by different use of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

	SA	SBC	SCS	ABC
Total area (km^2)	175.00	406.00	15.00	596.00
% of green area	35.78%	46.97%	0.00%	42.50%
Green area (km^2)	62.62	190.70	0	253.31
% of urban area	64.22%	53.03%	100%	57.50%
Urban area (km^2)	112.39	215.30	15.00	342.69
% commercial area	34.44%	48.86%	31.72%	24.94%
Commercial area (km^2)	38.71	105.20	4.76	148.66
% residential area	65.54%	51.14%	68.28%	32.55%
Residential area (km^2)	73.66	110.11	10.24	194.00

Table E3 – Detailed calculation of the constructed area by type of occupation in Santo André and São Bernardo do Campo.

Type of occupation	Maximum number of floors allowed	% of urban area	Area (km^2)	Constructed area (m^2)(*)
		Santo André		
A	2	3.77%	4.24	5.93×10^{06}
B	4	30.67%	34.47	1.10×10^{08}
C	11	32.89%	36.96	3.25×10^{08}
D	16	3.33%	3.74	4.79×10^{07}
E	21	21.77%	24.47	4.11×10^{08}
F	30	6.00%	6.74	1.62×10^{08}
G (no restriction)	30 (considered)	1.55%	1.74	4.18×10^{07}
Total constructed area				$\mathbf{1.10 \times 10^{09}}$
		São Bernardo do Campo(**)		
A	2	18.86%	40.61	5.68×10^{07}
B	4	30.00%	64.59	1.81×10^{08}
C	11	25.66%	55.25	4.25×10^{08}
D	16	2.60%	5.59	6.27×10^{07}
E	21	16.99%	36.57	5.38×10^{08}
F	30	4.68%	10.08	2.12×10^{08}
G (no restriction)	30 (considered)	1.21%	2.60	5.47×10^{07}
Total constructed area				$\mathbf{1.53 \times 10^{09}}$

(*) considering occupation of 70% of the land. Constructed area = Area x number of floors x 0.7
(**) considering the same standard of Santo André, due to the lack of information regarding number of floors.

Table E4 – Detailed calculation of the constructed area by type of occupation in São Caetano do Sul.

Type of occupation	Estimate number of floors	% of urban area	Area (km^2)	Constructed area (m^2)(*)
		Santo André		
Residential low density	3	34.35%	5.15	1.08×10^{07}
Residential low and medium density	8	33.92%	5.09	2.85×10^{07}
Commercial area	4	31.72%	4.76	1.33×10^{07}
Total constructed area				$\mathbf{5.26 \times 10^{07}}$

(*) considering occupation of 70% of the land. Constructed area = Area x number of floors x 0.7

The total constructed area of each municipality shown in Table E3 and Table E4 was multiplied by the emergy per area value shown in Table E5 , to obtain its emergy.

$$\text{Emergy} = \text{constructed area} \times \text{emergy per area}$$

The emergy was then multiplied by the estimate turnover time of 25 years resulting the emergy of the stocks shown in Table 12.

Water stock calculation (Billings dam)

Table E5 – Calculation of the emergy of water stock of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

	SA	SBC	SCS	ABC
Total area (km^2)	175.00	406.00	15.00	596.00
Area of the dam inside the municipality (m^2)(*)	6.85×10^{06}	7.58×10^{07}	0.00×10^{00}	8.27×10^{07}
Percentage of the dam inside the municipality	5.40%	59.79%	0.00%	65.20%
Volume of the dam inside the municipality (m^3)	6.21×10^{07}	6.87×10^{08}	0.00×10^{00}	7.49×10^{08}
Mass of water inside the municipality (kg)	6.21×10^{10}	6.87×10^{11}	0.00×10^{00}	7.49×10^{11}
Energy of water inside the municipality (J)	3.10×10^{11}	3.43×10^{12}	0.00×10^{00}	3.74×10^{12}
Emergy of water inside the municipality (sej)	2.14×10^{16}	2.37×10^{17}	0.00×10^{00}	2.58×10^{17}
Emergy of water inside the municipality x Turnover (sej)	6.13×10^{16}	6.79×10^{17}	0.00×10^{00}	7.40×10^{17}

(*) Area of the dam inside the municipality was calculated by observation of maps found at the city council websites.

Area of the dam inside the municipality = Total area of the dam x percentage of the dam inside the municipality

Total area of the dam = 1.27×10^8 m^2 (Rocca, 1995)

Volume of the dam inside the municipality = Total volume of the dam x percentage of the dam inside the municipality

Total volume of the dam (at full capacity) = 1.27×10^9 m^3 (Rocca, 1995)

Mass of water inside the municipality = Volume of the dam inside the municipality x density of water (1,000 kg/m^3).

Energy of water inside mun. = Mass of water inside mun. x Gibbs number

Gibbs number = 5 J/g

Emergy of water inside mun. = Energy of water inside mun. x Transformity

Transformity of the water storage = 4.10×10^4 sej/J (Odum, 1996)

Emergy of the stock of water inside mun. = Emergy of water inside mun. x Turnover time

$$\text{Turnover Time} = \frac{\text{Storage}}{\frac{\text{inflow}+\text{outflow}}{2}}$$

Inflow = 20.7 m^3/s (Rocca, 1995)

Outflow = 4.7 m^3/s (Rocca, 1995)

Total volume of the dam (at full capacity) = 1.27×10^9 m^3 (Rocca, 1995)

Turnover time = 90,452,756 s = 2.87 years

Biomass stock calculation

Table E6 – Calculation of the biomass stock of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

	SA	SBC	SCS	ABC
Total area (km^2)	175.00	406.00	15.00	596.00
% of green area	35.78%	46.97%	0.00%	42.50%
Green area (km^2)	62.62	190.70	0	253.31
% of urban area	64.22%	53.03%	100%	57.50%
Urban area (km^2)	112.39	215.30	15.00	342.69
% of forest(*)	1.74%	3.70%	0.00%	3.03%
Forest area (km^2)	3.05	15.02	0.00	18.07
Energy of forest (J/yr)	6.58×10^{13}	3.24×10^{14}	0.00×10^{00}	3.90×10^{14}
Emergy of forest (sej)	3.64×10^{17}	1.80×10^{18}	0.00×10^{00}	2.16×10^{18}
Emergy of forest x Turnover Time (sej)	7.29×10^{20}	3.60×10^{21}	0.00×10^{00}	4.32×10^{21}
% of Capoeira(*)	34.00%	43.26%	0.00%	39.45%
Capoeira area (km^2)	59.50	175.64	0.00	235.14
Energy of capoeira (J/yr)	4.52×10^{14}	1.33×10^{15}	0.00×10^{00}	1.79×10^{15}
Emergy of capoeira (sej)	1.93×10^{18}	5.69×10^{18}	0.00×10^{00}	7.61×10^{18}
Emergy of capoeira x Turnover Time (sej)	5.78×10^{18}	1.71×10^{19}	0.00×10^{00}	2.28×10^{19}

(*) map of green area (Sec. do meio ambiente, 2009)

Energy of forest = green area x net primary production (NPP) of forest

Energy of forest = (______m^2) x (______J/m^2 x yr)

NPP of forest = 2.16×10^{07} J/m^2 yr (Lu et al., 2006)

Emergy of forest = Energy of forest x Transformity of forest

Transformity of forest = 5.54×10^{03} sej/J (Lu et al., 2006)

Emergy of stock of forest = Emergy of forest x Turnover time of forest

Turnover time of forest = 100 yr (estimate)

Energy of Capoeira = green area x net primary production (NPP) of Capoeira*

*Capoeira is a type of vegetation very similar to grass. The NPP, transformity and turnover time were considered the same of grass

Energy of Capoeira = (______m^2) x (______J/m^2 x yr)

NPP of Capoeira = 7.60×10^{06} J/m^2 yr (Lu et al., 2006)

Emergy of Capoeira = Energy of Capoeira x Transformity of Capoeira

Transformity of Capoeira = 4.26×10^{03} sej/J (Lu et al., 2006)

Emergy of stock of Capoeira = Emergy of Capoeira x Turnover time of Capoeira

Turnover time of Capoeira = 3 yr (considered the same of Savanna, Brown and Bardi, 2001)

Fleet stock calculation

Table E7 – Calculation of the fleet stock of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

Vehicle type	SA	SBC	SCS	ABC
Regular car	**288,100**	**299,434**	**84,655**	**672,189**
Emergy of cars (sej)	3.14×10^{21}	3.26×10^{21}	9.22×10^{20}	7.32×10^{21}
Emergy of cars x Turnover time(sej)	2.20×10^{22}	2.28×10^{22}	6.46×10^{21}	5.13×10^{22}
Truck	**8,359**	**10,303**	**2,679**	**21,341**
Emergy of truck (sej)	2.43×10^{20}	2.99×10^{20}	7.78×10^{19}	6.20×10^{20}
Emergy of truck x Turnover time(sej)	2.43×10^{21}	2.99×10^{21}	7.78×10^{20}	6.20×10^{21}
Pick-up truck	**18,950**	**20,400**	**6,478**	**45,828**
Emergy of pick-up truck (sej)	2.64×10^{20}	2.85×10^{20}	9.04×10^{19}	6.39×10^{20}
Emergy of pick-up truck x Turnover time(sej)	1.85×10^{21}	1.99×10^{21}	6.32×10^{20}	4.47×10^{21}
Motorcycle	**45,656**	**47,004**	**8,900**	**101,560**
Emergy of motorcycle (sej)	1.75×10^{19}	1.80×10^{19}	3.40×10^{18}	3.88×10^{19}
Emergy of motorcycle x Turnover time(sej)	6.98×10^{19}	7.19×10^{19}	1.36×10^{19}	1.55×10^{20}
Scooter	**5,530**	**6,647**	**1,514**	**13,691**
Emergy of scooter (sej)	1.59×10^{18}	1.91×10^{18}	4.34×10^{17}	3.93×10^{18}
Emergy of scooter x Turnover time(sej)	6.34×10^{18}	7.62×10^{18}	1.74×10^{18}	1.57×10^{19}

IBGE (2013)

Table E8 – Calculation of the emergy of the vehicles that compound the fleet of ABC Paulista.

Material	UEV (sej/kg)(*)	Generic Sedan			Truck			Pickup truck		
		%	Mass (kg)	Emergy (sej)	%	Mass (kg)	Emergy (sej)	%	Mass (kg)	Emergy (sej)
Plastic	9.68×10^{12}	9.3%	143.00	1.38×10^{15}	9.3%	356.19	3.45×10^{15}	9.3%	170.97	1.66×10^{15}
Nonferrous metal (**)	7.76×10^{11}	9.0%	138.00	1.07×10^{14}	9.0%	344.70	2.67×10^{14}	9.0%	165.46	1.28×10^{14}
Metal ferrous (**)	3.16×10^{12}	64.0%	985.00	3.11×10^{15}	64.0%	2,451.20	7.75×10^{15}	64.0%	1,176.58	3.72×10^{15}
Fluids (**)	6.38×10^{11}	4.8%	74.00	4.72×10^{13}	4.8%	183.84	1.17×10^{14}	4.8%	88.24	5.63×10^{13}
Rubber (**)	6.38×10^{11}	6.9%	105.00	6.70×10^{13}	6.9%	264.27	1.69×10^{14}	6.9%	126.85	8.10×10^{13}
Glass	3.50×10^{12}	2.8%	42.00	1.47×10^{14}	2.8%	107.24	3.75×10^{14}	2.8%	51.48	1.80×10^{14}
Other materials (**)	1.34×10^{14}	3.3%	45.00	6.03×10^{15}	3.3%	126.39	1.69×10^{16}	3.3%	60.67	8.13×10^{15}
		Total	**1,532.00**	**1.09×10^{16}**	**Total**	**3,830.00**	**2.91×10^{16}**	**Total**	**1,838.4**	**1.39×10^{16}**

Material	UEV (sej/kg)(*)	Motorcycle			Scooter		
		%	Mass (kg)	Emergy (sej)	%	Mass (kg)	Emergy (sej)
Plastic	9.68×10^{12}	6.0%	7.20	6.97×10^{13}	6.0%	5.40	5.23×10^{13}
Nonferrous metal (**)	7.76×10^{11}	7.0%	8.40	6.52×10^{12}	7.0%	6.30	4.89×10^{12}
Metal ferrous (**)	3.16×10^{12}	78.0%	93.60	2.96×10^{14}	78.0%	70.20	2.22×10^{14}
Fluids (**)	6.38×10^{11}	3.0%	3.60	2.30×10^{12}	3.0%	2.70	1.72×10^{12}
Rubber (**)	6.38×10^{11}	5.0%	6.00	3.83×10^{12}	5.0%	4.50	2.87×10^{12}
Glass	3.50×10^{12}	1.0%	1.20	4.20×10^{12}	1.0%	0.90	3.15 x 1012
Other materials (**)	1.34×10^{14}	0.0%	0.00	0.00×10^{00}	0.0%	0.00	0.00×10^{00}
		Total	**120.00**	**3.82×10^{14}**	**Total**	**90.00**	**2.87×10^{14}**

(*) – UEVs found in Table 2.
(**) – Transformity of nonferrous metal was considered the same of aluminum; transformity of metal ferrous was considered the same of steel and iron; transformities of fluids and rubber were considered the same of chemicals; other materials were considered to be textiles.

Composition of a generic sedan vehicle (Sullivan et al., 1998).

Truck was considered to be 2.5 times heavier than a generic sedan and Pickup truck 20% heavier than a generic sedan, keeping the same percentages of each material. Estimated composition and mass of a regular 125 cc motorcycle. Scooter.considered to be 20% lighter than a regular 125 cc motorcycle.

Population stock calculation

Table E9 - Calculation of the emery/individual of SP state

Population type	SP state	
	Individuals(*)	**Emergy/individual (sej/person)**
Child 0-4 yo	2,678,908	1.56×10^{22}
Child 5-9 yo	2,860,037	1.50×10^{22}
Person more than 10 yo illiterate	14,974,003	1.32×10^{22}
Person more than 10 yo incomplete high school	6,705,105	1.57×10^{22}
Person more than 10 yo incomplete high school and incomplete graduation	9,577,012	1.76×10^{22}
Person more than 10 yo complete graduation	4,171,221	2.02×10^{22}
Person more than 10 yo undefined	295,914	1.80×10^{22}
	2,678,908	**1.15×10^{23}**
Emergy of the stock		**8.07×10^{24}**

(*) considers the employed and unemployed individuals. Census 2010, (IBGE 2013).

$$\text{Emergy/individual (seJ/person)} = \frac{\text{Emergy of SP state}}{\text{number of individuals per category}}$$

Emergy of SP state = 8.44×10^{23} sej/yr (Demétrio, 2011)

Table E10 – Population stock of Santo André, São Bernardo do Campo, São Caetano do Sul and ABC as a whole.

Population type	SA		SBC		SCS		ABC	
	Individuals	**Emergy (sej)**	**Individuals**	**Emergy (sej)**	**Individuals**	**Emergy (sej)**	**Individuals**	**Emergy (sej)**
Child 0-4 yo	39,826	1.25×10^{22}	49,373	1.56×10^{22}	6,972	2.20×10^{21}	96,171	3.03×10^{22}
Child 5-9 yo	41,331	1.22×10^{22}	50,662	1.50×10^{22}	7,295	2.15×10^{21}	99,288	2.93×10^{22}
Person more than 10 yo illiterate	203,427	1.15×10^{22}	234,519	1.32×10^{22}	37,946	2.14×10^{21}	475,892	2.68×10^{22}
Person more than 10 yo incomplete high school	104,493	1.32×10^{22}	124,615	1.57×10^{22}	20,483	2.58×10^{21}	249,591	3.14×10^{22}
Person more than 10 yo incomplete high school and incomplete graduation	186,379	1.64×10^{22}	199,926	1.76×10^{22}	40,621	3.58×10^{21}	426,926	3.76×10^{22}
Person more than 10 yo complete graduation	96,855	1.96×10^{22}	100,053	2.02×10^{22}	35,294	7.14×10^{21}	232,202	4.70×10^{22}
Person more than 10 yo undefined	4,097	1.17×10^{22}	6,316	1.80×10^{22}	653	1.86×10^{21}	11,066	3.16×10^{22}
	Total	**9.71×10^{22}**	**Total**	**1.15×10^{23}**	**Total**	**2.17×10^{22}**	**Total**	**2.34×10^{23}**
Emergy of the stock		**6.79 x 1024**		**8.07×10^{24}**		**1.52×10^{24}**		**1.64×10^{25}**

Census 2010, (IBGE 2013).

Appendix F

In this appendix are shown calculations for the sensibility analysis for Santo André, São Bernardo do Campo, São Caetano do Sul.

Table F1 – Sensibility analysis of the transformities for Santo André.

	Item	Units	Quantity	UEV (sej/unit)	Emergy (sej/year)	Percentage of the total emergy	UEV reference	New U using this UEV	Variation created at U
10a-1	Natural gas	J/yr	1.14×10^{16}	6.84×10^{04}	7.80×10^{20}	5.4%	Bastianoni et al., 2005	NA	NA
10a-2	Natural gas	J/yr	1.14×10^{16}	1.18×10^{05}	1.35×10^{21}	8.9%	Odum, 1996	1.51×10^{22}	3.76%
10a-3	Natural gas	J/yr	1.14×10^{16}	8.11×10^{04}	9.25×10^{20}	6.3%	Brown and Bardi, 2001	1.47×10^{22}	1.15%
10b-1	Gasoline	J/yr	4.63×10^{15}	1.11×10^{05}	5.13×10^{20}	3.5%	Odum, 1996	NA	NA
10b-2	Gasoline	g/yr	1.23×10^{11}	4.99×10^{09}	6.16×10^{20}	4,2%	Bastianoni et al., 2009	1.47×10^{22}	1.15%
11-1	Electricity (Total)	J/yr	9.97×10^{15}	2.77×10^{05}	2.76×10^{21}	19.0%	Odum, 1996	NA	NA
11-2	Electricity (Total)	J/yr	9.97×10^{15}	3.11×10^{05}	3.10×10^{21}	21.3%	Brown and Ulgiati, 2004	1.49×10^{22}	2.47%
11-3	Electricity (Total)	J/yr	9.97×10^{15}	2.07×10^{05}	2.06×10^{21}	14.9%	Pulselli et al., 2008	1.39×10^{22}	-4.54%
13-1	Food	J/yr	3.09×10^{15}	1.43×10^{05}	4.41×10^{20}	3.0%	Brown and McClanahan, 1996	NA	NA
13-2	Food	J/yr	3.09×10^{15}	1.73×10^{05}	5.54×10^{20}	3.6%	Brown and Prado-Jatar	1.47×10^{22}	1.15%
23-1	Plastic	kg/yr	5.49×10^{07}	9.68×10^{12}	5.32×10^{20}	3.7%	Brown and Arding, 1991	NA	NA
23-2	Plastic	kg/yr	5.49×10^{07}	5.72×10^{12}	3.14×10^{20}	2.2%	Buranakarn, 1998	1.43×10^{22}	-1.62%
23-3	Plastic	kg/yr	5.49×10^{07}	5.90×10^{12}	3.24×10^{20}	2.3%	Lou and Ulgiati, 2013	1.43×10^{22}	-1.62%

Table F2 – Sensibility analysis of the transformities for São Bernardo do Campo.

	Item	Units	Quantity	UEV (sej/unit)	Emergy (sej/year)	Percentage of the total emergy	UEV reference	New U using this UEV	Variation created at U
10c-1	Diesel	J/yr	5.22×10^{15}	1.11×10^{05}	5.79×10^{20}	2.5%	Odum, 1996	NA	NA
10c-2	Diesel	J/yr	5.22×10^{15}	4.58×10^{05}	2.39×10^{21}	9,7%	Abel, 2000	2.46×10^{22}	7.32% (*)
11-1	Electricity (Total)	J/yr	9.53×10^{15}	2.77×10^{05}	2.64×10^{21}	11.6%	Odum, 1996	NA	NA
11-2	Electricity (Total)	J/yr	9.53×10^{15}	3.11×10^{05}	2.96×10^{21}	12.8%	Brown and Ulgiati, 2004	2.31×10^{22}	1.30%
11-3	Electricity (Total)	J/yr	9.53×10^{15}	2.07×10^{05}	1.97×10^{21}	8.9%	Pulselli et al., 2008	2.21×10^{22}	-3.17%
17b-1	Fish	kg/yr	2.17×10^{06}	2.78×10^{14}	6.04×10^{20}	2.7%	Odum, 1996	NA	NA
17b-2	Fish	kg/yr	2.17×10^{06}	1.23×10^{13}(**)	2.67×10^{19}	0.1%	After Cavallet et al., 2006	2.22×10^{22}	-2.70%
17b-3	Fish	kg/yr	2.17×10^{06}	5.07×10^{11}(**)	1.10×10^{18}	<0.1%	After Genoni et al., 2003	2.22×10^{22}	-2.70%
26-1	Machinery	kg/yr	1.02×10^{08}	1.12×10^{13}	1.15×10^{21}	5.0%	Brown and Bardi, 2001	NA	NA
26-2	Machinery	kg/yr	1.02×10^{08}	2.22×10^{13}	2.27×10^{21}	9.5%	Lou and Ulgiati, 2013	2.39×10^{22}	4.60%
26-3	Machinery	kg/yr	1.02×10^{08}	1.16×10^{13}	1.19×10^{21}	5.2%	Buranakarn, 1998	2.28×10^{22}	0.00%

(*) This variation above 5% is not relevant since the other reference for Diesel (Odum, 1996) is widely used and reliable.

(**) Energy content of Pescada fish = 97kcal/100g = 4,061.20J/g

UEV Cavallet et al., 2006 = 3.04×10^{06}sej/J

Resulting UEV = 1.23×10^{13}sej/kg

UEV Genoni et al., 2003 = 1.25×10^{05}sej/J

Resulting UEV = 5.07×10^{11}sej/kg

Table F3 – Sensibility analysis of the transformities for São Caetano do Sul.

	Item	Units	Quantity	UEV (sej/unit)	Emergy (sej/year)	Percentage of the total emergy	UEV reference	New U using this UEV	Variation created at U
10b-1	Gasoline	J/yr	1.53×10^{15}	1.11×10^{05}	1.69×10^{20}	4.3%	Odum, 1996	NA	NA
10b-2	Gasoline	J/yr	1.53×10^{15}	4.99×10^{09}	2.03×10^{20}	5.2%	Bastianoni et al., 2009	3.94×10^{21}	1.02%
11-1	Electricity (Total)	J/yr	2.28×10^{15}	2.77×10^{05}	6.31×10^{20}	16.2%	Odum, 1996	NA	NA
11-2	Electricity (Total)	J/yr	2.28×10^{15}	3.11×10^{05}	7.08×10^{20}	17.8%	Brown and Ulgiati, 2004	3.98×10^{21}	2.01%
11-3	Electricity (Total)	J/yr	2.28×10^{15}	2.07×10^{05}	4.71×10^{20}	12.6%	Pulselli et al., 2008	3.74×10^{21}	-4.28%
17b-1	Fish	kg/yr	2.17×10^{06}	2.78×10^{14}	6.04×10^{20}	5.5%	Odum, 1996	NA	NA
17b-2	Fish	kg/yr	2.17×10^{06}	1.23×10^{13}(*)	2.67×10^{19}	0.3%	After Cavallet et al., 2006	3.70×10^{21}	-5.41%
17b-3	Fish	kg/yr	2.17×10^{06}	5.07×10^{11}(**)	1.10×10^{18}	0.0%	After Genoni et al., 2003	3.69×10^{21}	-5.69%
26-1	Machinery	kg/yr	1.13×10^{07}	1.12×10^{13}	1.26×10^{20}	3.2%	Brown and Bardi, 2001	NA	NA
26-2	Machinery	kg/yr	1.13×10^{07}	2.22×10^{13}	2.51×10^{20}	6.2%	Lou and Ulgiati, 2013	4.03×10^{21}	3.23%
26-3	Machinery	kg/yr	1.13×10^{07}	1.16×10^{13}	1.31×10^{20}	3.4%	Buranakarn, 1998	3.91×10^{21}	0.26%

(*) Energy content of Pescada fish = 97kcal/100g = 4,061.20J/g

UEV Cavallet et al., 2006 = 3.04×10^{06}sej/J

Resulting UEV = 1.23×10^{13}sej/kg

(**)Energy content of Pescada fish = 97kcal/100g = 4,061.20J/g

UEV Genoni et al., 2003 = 1.25×10^{05}sej/J

Resulting UEV = 5.07×10^{11}sej/kg

Table F4 – Sensibility analysis of the topsoil loss calculation for ABC Paulista.

	Item	Units	Quantity	UEV (sej/unit)	Emergy (sej/year)	Percentage of the total emergy	UEV reference	New U using this method	Variation created at U
9-1	Topsoil loss	J/yr	6.62×10^{07}	1.24×10^{05}	8.22×10^{12}	<0.1%	Odum, 1996	NA	NA
9-2	Topsoil loss	J/yr	2.68×10^{10}	1.24×10^{05}	3.33×10^{15}	<0.1%	Odum, 1996	4.11×10^{22}	<0.1%

Appendix G

In this appendix are shown calculations and tables for the support areas. SA was taken as an example for the calculations. The same procedure was used for SBC, SCS and ABC as a whole.

Renewable support area

$SA_{(r)} = \frac{F+N}{Empd_{(r)}}$ where $SA_{(r)}$ is the renewable support area and $Empd_{(r)} = \frac{R}{Area}$

$$SA_{(r\,SA)} = \frac{2.81x10^{16} + 1.45x10^{22}}{Empd_{(r\,SA)}} \qquad Empd_{(r\,SA)} = \frac{R}{Area_{SA}} = \frac{2.76x10^{19}}{1.75x10^{8}} = 1.58x10^{11}\ \frac{sej}{m^2\ yr}$$

$$SA_{(r\,SA)} = \frac{2.81x10^{16} + 1.45x10^{22}}{1.58x10^{11}} = 9.20x10^{10}\ m^2$$

Renewable support area of Atlantic forest

$$SA_{(r\ atltantic\ forest)} = \frac{F+N}{Empd_{(atltantic\ forest)}}$$

Where:

$SA_{(r\ atlantic\ forest)}$ is the renewable support area using emergy and NPP.

$Empd_{(atlantic\ forest)} = NPP_{energy\ density}$ x UEV

And $NPP_{energy\ density}$ = Dry biomass energy content x NPP

NPP is the net primary production of an Atlantic forest = 0.930 kg/m^2 yr (Orrell, 1998).

UEV is the transformity of forest biomass (sej/J) = 2.59 x 10^3 sej/J (Orrell, 1998).

$$NPP = \frac{0.930\ kg}{m^2\ yr} \qquad \text{Dry biomass energy content} = 3{,}600\frac{kcal}{kg}$$

$$NPP_{energy\ density} = 0.930\frac{kg}{m^2 yr}\ x\ 3{,}600\frac{kcal}{kg}\ x\ 4186\frac{J}{kcal} = 1.40x10^{7}\ \frac{J}{m^2 yr}$$

$$Empd_{(atltantic\ forest)} = 1.40x10^{7}\ \frac{J}{m^2 yr}\ x\ 2.59x10^{3}\ \frac{sej}{J} = 3.63x10^{10}\ \frac{sej}{m^2 yr}$$

$$SA_{(r\ atltantic\ forest\ SA)} = \frac{2.81x10^{16} + 1.45x10^{22}}{3.63x10^{10}} = 4.00x10^{11} m^2$$

Support area required to balance SA with the ELR of São Paulo state

$$SA_{(ELR\ SA)} = \frac{R^*}{Empd_{(r\ SA)}}$$

where $R^* = \frac{F+N}{ELR_{SP\ state}}$ and $ELR_{SP\ state}$ = 6.68 (Demétrio, 2011)

$$R^* = \frac{2.81x10^{16} + 1.45x10^{22}}{6.68} = 2.17x10^{21}$$

$$SA_{(ELR\ SA)} = \frac{2.17x10^{21}}{1.58x10^{11}} = 1.38x10^{10}\ m^2$$

Support area required to balance SA with the ELR of Brazil state

$$SA_{(ELR\ BR)} = \frac{R^*}{Empd_{(r\ BR)}}$$

where $R^* = \frac{F+N}{ELR_{BR}}$ and ELR_{BR} = 1.29 (Demétrio, 2011)

$$R^* = \frac{2.81x10^{16} + 1.45x10^{22}}{1.28} = 1.13x10^{22}$$

$$SA_{(ELR\ SA)} = \frac{1.13x10^{22}}{1.58x10^{11}} = 7.13x10^{10}\ m^2$$

Appendix H

In this appendix are shown calculations and tables for the emergy benefit ratios. SA was taken as an example for the calculations. The same procedure was used for SBC, SCS and ABC as a whole.

Emergy benefit ratio considering GDP

$$EBR_{GDP} = \frac{\text{Emergy of total exports}}{\text{Emergy of the GDP}} \qquad EBR_{GDP\ SA} = \frac{1.01 x 10^{22}}{1.46 x 10^{22}} = 0.694$$

Emergy benefit ratio considering total exports

$$EBR_{tot.\ exp.} = \frac{\text{Emergy of total exports}}{\text{Emergy of the money received by total exports}}$$

$$EBR_{tot.\ exp.\ SA} = \frac{1.01 x 10^{22}}{4.49 x 10^{21}} = 2.247$$

Emergy benefit ratio considering internal exports

$$EBR_{int.\ exp.} = \frac{\text{Emergy of internal exports}}{\text{Emergy of the money received by internal exports}}$$

$$EBR_{int.\ exp.\ SA} = \frac{5.36 x 10^{21}}{3.25 x 10^{21}} = 1.651$$

Emergy benefit ratio considering external exports

$$EBR_{ext.\ exp.} = \frac{\text{Emergy of external exports}}{\text{Emergy of the money received by external exports}}$$

$$EBR_{ext.\ exp.\ SA} = \frac{4.45 x 10^{21}}{1.26 x 10^{21}} = 3.539$$