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Study of the Environmental Sustainability of São Caetano do Sul Using Emergy Synthesis

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ABSTRACT

Cities are the focal point of several activities, being them commercial, industrial, social, economic or politics. 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 is a powerful tool to environmental accounting and measures both natural and human resources to generate products and services. The evaluation through emergy synthesis of cities, states, nations and its base resources provides large scale perspective to the evaluation of urban areas and can help selection of policies for public benefit. This study applies the emergy synthesis to assess the sustainability of São Caetano do Sul (SCS), a relatively small city with approximately 152,000 inhabitants, which is part of Greater São Paulo, Brazil. SCS is considered to be a prosperous city, and it has one of the best human development indexes of the country. The city holds important industrial activity, and housing facilities.

INTRODUCTION

Cities are centers of various activities, which have an impact on the biosphere as primary consumers of resources and environmental services supplied from outside the cities' 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. The permanence of a city and its internal structure depend on the flow of products and services into and out of it (Huang et al., 2009). Hence, there must be a steady flow of energy, coming from various locations in the biosphere, in the form of materials, people, information and others crossing the boundaries of the municipality.

There are severe limits to the substitutability of manufactured for natural capital due to environmental characteristics as irreversibility, uncertainty and the existence of critical components of natural capital, which contribute to welfare (Daly, 1991). Through emergy accounting, 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 or the social assessment performed by the human development index. 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 use of emergy accounting has already been explored by many researchers for the study of urban systems. Emergy evaluation of states, nations and their resource basis gives large-scale perspective to valuation of environmental areas, and helps to select policies for public benefit (Odum, 1996). Ascione et al. (2009) studied the sustainability of Rome and compared with the sustainability values of Italy. Zhang et al. (2009) studied the metabolism of Beijing based on the emergy synthesis. Lei et al. (2008) evaluated the dynamic urban system and the economic development of Macao. Huang (1998) has developed standards of urban sustainability indicators for Taiwan. A standard for integrated regional studies through a spatial analysis based on emergy in the province of Cagliari in Italy was developed by Pulselli et al. (2007).

SCS is a prosperous city, and it has one of the highest human development indexes of the country. It holds relevant industrial activity and housing facilities, deserving a more detailed study regarding its environmental sustainability. This study uses emergy synthesis to assess the environmental sustainability of SCS.

METHODOLOGY

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; CRESESB, 2010; SECEX, 2011; SEADE, 2011). References of emergy unit values (UEV) are shown in table 1.

The indirect area defined as the ‘‘renewable support area’’ ($SA_{(r)}$) (Brown and Ulgiati, 2001) was calculated according to Equation 1 and the support area required to balance the system of interest with the ELR of the region (state of São Paulo) was estimated according to Equation 2:

$$SA_{(r)} = (N + F) / E_{mpd(r)} \quad \text{(Eq.1)}$$

$$SA_{(ELR)} = R^* / E_{mpd(r)} \quad \text{(Eq.2)}$$

Where: $E_{mpd(r)}$ is renewable empower density of the region (seJ/year); N is non-renewable inputs (seJ/year); F is purchased inputs (seJ/year); $R^* = (N + F)/ELR_{(r)}$; and $ELR_{(r)}$ is environmental loading ratio of the region. Values of $E_{mpd(r)} = 4.4 \times 10^{11}$ seJ/year and the $ELR_{(r)} = 6.68$ for São Paulo state were taken from (Demétrio, 2011).

Using the concept of ecological overshoot (or simply overshoot), the use of resources (appropriation) is compared with the availability of local resources (carrying capacity). The main idea of this concept is that for some time it is possible to keep a system in overshoot, but if this condition

Table 1. References of emergy unit values (UEV) used in this text.

Item	**UEV (seJ/unit)**	**Ref.**
Solar radiation	1	Odum, 1996
Rain (Chemical energy)	3.05×10^{04}	Odum, 1996
Rain (Geopotential energy)	4.70×10^{04}	Odum, 1996
Kinetic wind energy	2.45×10^{03}	Odum, 1996
Geothermal heat	5.80×10^{04}	Odum, 1996
Natural gas	8.06×10^{04}	Odum, 1996
Gasoline	1.11×10^{05}	Odum, 1996
Diesel oil	1.11×10^{05}	Odum, 1996
Sugarcane Ethanol	4.87×10^{04}	Pereira et al., 2009
Electricity	2.77×10^{05}	Odum, 1996
Treated water	7.75×10^{08}	Buenfil, 2001
EMR of the state of São Paulo	1.68×10^{12}	Demétrio, 2011
Food	1.43×10^{05}	Brown et al., 1996

continues the system will collapse, since the resilience of the system will be beaten. To avoid collapsing the system must receive external services or resources that keep it working, but may be leading other regions to the overshoot condition. The calculation of the areas using the local renewable resources is a way to estimate the carrying capacity appropriation ($CCA_{(R)}$, in area) of a given region, supposing the complete substitution of the F and N flows by R. To calculate the appropriated area considering the local conditions and the surrounding region's environmental stress ($CCA_{(ELR)}$), the F and N flows are substitute by R flows up to the point when it reaches the environmental loading ratio of the region. 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.

RESULTS AND DISCUSSIONS

SCS is one of the 39 municipalities that form Greater São Paulo, a large metropolitan area located in the state of São Paulo in the Southeast region of Brazil (Figure 1). Located almost in the center of the largest metropolitan area in South America, SCS was surrounded and limited over time by the urban growth of the capital and other highly urbanized centers (São Bernardo do Campo and Santo André). The city does not have rural areas and currently has no place for expansion other than vertical growth. The city green area is due to reforestation projects and accounts for 0.14% of the total area. The major part of economical activities is related to services and automotive industry.

Figure 2 shows the energy systems diagram of SCS. The city imports virtually all the resources it uses from outside its borders (water, fuel, electricity, machinery, products, and services), and due to the small territory it occupies, receives proportionately small amounts of renewable resources (rain, wind and sun). Industrial and manufacturing activities use the built environment, and generate a stock of capital that is represented within the diagram.

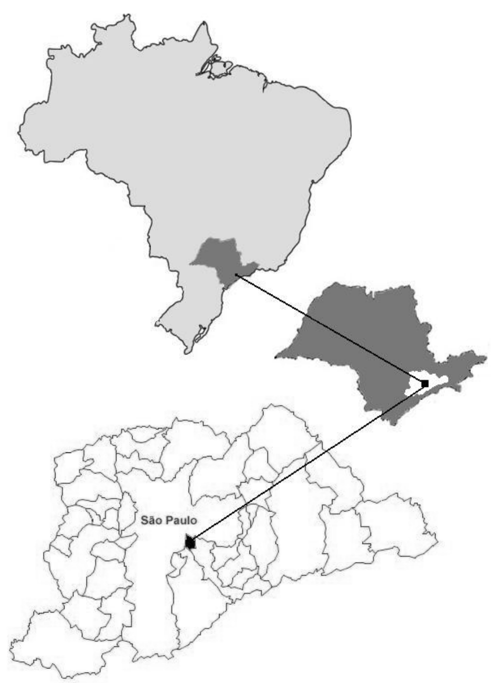

Figure 1. *Map of Brazil showing São Paulo State and SCS inside Great São Paulo.*

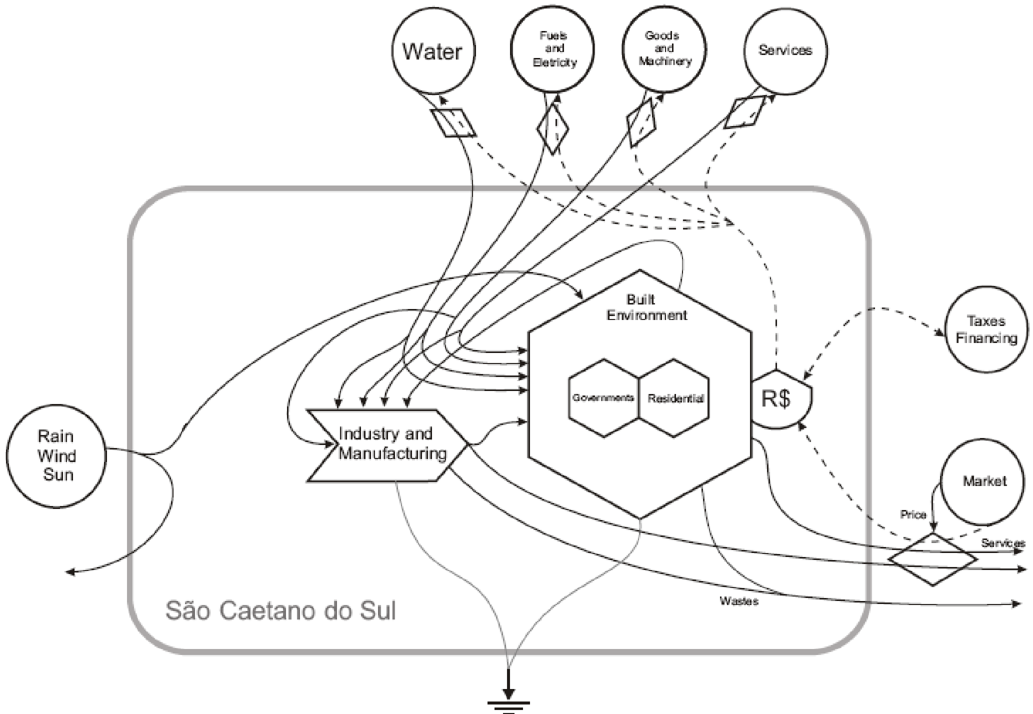

Figure 2. *Energy system diagram of São Caetano do Sul.*

Table 2 shows the emergy flows for SCS. Calculations of the gross energy of each resource are shown in the appendix. Renewable resources are composed by items 2 and 3, called total water (NEAD, 2000), plus the geothermal heat (item 5). Imported resources correspond to the sum of items 6 to 13. Exports were accounted using monetary statistics provided by the Brazilian Foreign Trade Services (SECEX, 2011).

Results show that the contribution of renewable resources to São Caetano do Sul is composed by rain (89% seJ/seJ) and geothermal heat (11% seJ/seJ), which contribute with only 0.2% to the total emergy (Table 2). Among the imported resources, services, electricity and machines/equipments are the most significant inputs. Services stands for 82%, electricity contributes with 8% seJ/seJ, and machines/equipments stand for little more that 2.5% of São Caetano do Sul total emergy. It is clear that São Caetano do Sul is totally dependent on imported resources (F), which is a characteristic of urban centers that concentrate activities that require resources provided by various locations coming from outside their boundaries. The high value of purchased resources compensates the scarce natural resources inputs. Table 3 shows the emergy indices calculated for São Caetano do Sul.

As expected, the emergy indices show that the city has low emergy yield, a high environmental loading, and a very low sustainability index (items 22-25, Table 3). SCS has an Empower Density of 5.33 x 10^{14} seJ/m^2 year (item 15, Table 3), which is comparable to those calculated for other cities: Rome 1.07 x 10^{14} seJ/m^2 year (Ascione et al., 2009), Macao 8.04 x 10^{14} seJ/m^2 year (Lei et al., 2008), Taipei 5.32 x 10^{13} seJ/m^2 year (Huang, 1998) and San Juan 7.00 x 10^{13} seJ/m^2 year (Odum et al.,1995).

In Table 3, it is possible to distinguish various characteristics of the municipality. Comparing items 8 and 9, we observe that, despite the city being a major exporter of products for the automotive industry, the amount of exported products accounts for only 9% of total imports required to keep this industry and the municipality population. However, great part of the purchased resources is used directly by the industry that exports virtually all its products, and cannot be seen as a wealth factor to

Table 2. Matter, energy and emergy flows supporting the SCS urban system.

#	Item	Units	Quantity	UEV (seJ/unit)	Emergy (seJ/year)
	Renewable resources				
1(*)	Solar radiation	J/yr	6.47×10^{16}	1	6.47×10^{16}
2	Rain (Chemical energy)	J/yr	9.78×10^{13}	3.05×10^{04}	2.98×10^{18}
3	Rain (Geopotential energy)	J/yr	1.84×10^{14}	4.70×10^{04}	8.66×10^{18}
4(*)	Kinetic wind energy	J/yr	2.86×10^{13}	2.45×10^{03}	7.00×10^{16}
5	Geothermal heat	J/yr	2.55×10^{13}	5.80×10^{04}	1.48×10^{18}
	Total of renewable resources				$\mathbf{1.31 \times 10^{19}}$
	Imports				
6	Fuels				
6a	Natural gas	J/yr	8.43×10^{14}	8.06×10^{04}	6.79×10^{19}
6b	Gasoline	J/yr	1.53×10^{15}	1.11×10^{05}	1.69×10^{20}
6c	Diesel	J/yr	7.04×10^{14}	1.11×10^{05}	7.81×10^{19}
6d	Sugarcane Ethanol	J/yr	7.84×10^{14}	4.87×10^{04}	3.82×10^{19}
7	Electricity	J/yr	2.28×10^{15}	2.77×10^{05}	6.31×10^{20}
8	Treated water	m^3/yr	1.29×10^{10}	7.75×10^{08}	1.00×10^{19}
9	Machines and Equipments	USD/y	1.24×10^{08}	1.68×10^{12}	2.08×10^{20}
10	Services	USD/y	3.87×10^{09}	1.68×10^{12}	6.50×10^{21}
11	Food				
11a	Food (services)	USD/y	1.30×10^{07}	1.68×10^{12}	2.18×10^{19}
11b	Food	J/yr	6.97×10^{14}	1.43×10^{05}	9.97×10^{19}
12	Chemicals	USD/y	1.29×10^{06}	1.68×10^{12}	2.17×10^{18}
13	Others	USD/y	8.90×10^{07}	1.68×10^{12}	1.50×10^{20}
	Total of imports				$\mathbf{7.98 \times 10^{21}}$
	Exports				
14	Exports	USD/y	4.40×10^{08}	1.68×10^{12}	7.39×10^{20}
	Total of exports				$\mathbf{7.39 \times 10^{20}}$
	Total emergy				$\mathbf{7.99 \times 10^{21}}$

(*) not accounted to avoid double accounting (Odum, 1996).

** The values of EMergy per unit used in this table are based on the approximate planetary baseline of 15.83×10^{24} seJ/year (Odum, 2000).

its population (Table 2). The emergy per capita of 5.25×10^{16} seJ/pr year (item 16, Table 3), however, is comparable to those calculated for other cities: Rome 5.45×10^{16} seJ/pr year (Ascione et al., 2009), Macao 4.90×10^{16} seJ/pr year (Lei et al., 2008), Taipei 1.90×10^{16} seJ/pr year (Huang, 1998), San Juan 2.20×10^{16} seJ/pr year (Odum et al.,1995). This may mean that the emergy balance between population and industrial activities leans toward the latter.

Local renewable resources are scarce, and the city is totally dependent on external resources for their livelihood (Item 10). Considering its current living standard (Item 17), SCS would be able to support a population of only 250 people if only renewable resources were available. This population would be increased to 2,000 people (Item 18) if the living standards were similar to those of developed countries. For countries, the developed carrying capacity is calculated considering F/(R+N) = 8, but at urban scale results are substantially higher. Using the accounting done for Rome (Ascione et al., 2009), the F/(R+N) value is approximately 50. Rome is a high developed city with a high standard living. Using the value of 50 for SCS, the developed carrying capacity would be 12,600 people. Since the city counts with 152,000 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.

Table 3. Indices of emergy of SCS

Item	Name of Index	Expression (*)	Quantity
1	Renewable emergy flow	R	1.31×10^{19}
2	Flow from indigenous nonrenewable reserves	N	< 0.001
3	Flow of imported emergy	F+G+P2I	7.98×10^{21}
4	Total emergy inflows	R+N+F+G+P2I	7.99×10^{21}
5	Total emergy used, U	N0+N1+R+F+G+P2I	7.99×10^{21}
6	Total exported emergy	PE	7.39×10^{20}
7	Fraction emergy use derived from home sources	(NO+N1+R)/U	< 0.001
8	Imports minus exports	(F+G+P2I)-(PE)	7.24×10^{21}
9	Export to Imports	(PE)/(F+G+P2I)	0.09
10	Fraction used, locally renewable	R/U	0.002
11	Fraction of use purchased	(F+G+P2I)/U	1.00
12	Fraction imported service	P2I/U	0.82
13	Fraction of use that is free	(R+N0)/U	< 0.001
14	Ratio of concentrated to rural	(F+G+P2I+N1)/(R+N0)	NA
15	Use per unit area, Empower Density	U/(area)	5.33×10^{14}
16	Use per person	U/population	5.25×10^{16}
17	Renewable carrying capacity at present living standard	CITY POPULATION = (R/U) (population)	1.52×10^{05} 2.50×10^{02}
18	Developed carrying capacity at same living	8(R/U)(population)	2.00×10^{03}
19	Ratio of use to GNP, emergy/dollar ratio	P1=U/GNP	7.85×10^{11}
20	Ratio of electricity to use	(el)/U	7.90%
21	Fuel use per person	fuel/population	2.32×10^{15}
22	Emergy Investment Ratio	(F + G + P2I) /	609
23	Environmental Loading Ratio	(F+G+P2I+N0+N1) / R	609
24	Emergy Yield Ratio	U/(N0+N1+F+G+P2I)	609
25	Emergy Sustainability Index	EYR / ELR	0.002

(*) G is imported products; P2I is the emergy of imported services; N0 is rural resources; N1 is concentrated use; and GNP is the Gross National Product.

Table 4. 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 and Brazil)

	SCS (Direct area)	**Indirect area in São Paulo State**	**Indirect area in Brazil**
$SA_{(r)}$ (m^2)	9.14×10^{09}	1.81×10^{10}	1.92×10^{10}
$SA_{(ELR)}$ (m^2)	1.50×10^{07}	2.72×10^{09}	1.49×10^{10}

When it is hypothesized that all the environmental requirements to support a system are derived from renewable sources, an indirect area defined as the renewable support area ($SA_{(r)}$) can be calculated (Brown and Ulgiati, 2001). Its size will depend on the ability of the local environment to provide the necessary resources for the system on a renewable basis. Table 4 shows the indirect and support areas calculated in the case of SCS development model is extended to the state and the country. The calculations were performed disregarding the commercial flows to other places in Brazil, and the city's activities were attributed/distributed to the total population. Further studies are still necessary to discriminate these flows.

The difference between the direct area used (15 km^2) and the indirect required area (9140 km^2) shows that SCS would have to occupy an area about 600 times higher than its actual area to support its inhabitants exclusively with renewable resources (Table 4). Supposing that this area would be supplied by the renewable emergy flows of São Paulo state, SCS that occupies 0.006% of the state area, would have to count with 7% of this area to support its activities (including the industrial ones). On the other hand, if one considers that emergy renewable inflows are supplied by the country, SCS would need 0.2% of the Brazilian area. Thus, for predicting long-term sustainability, the $SA_{(r)}$ calculated establishes that SCS will need an area 1,100 times bigger than its actual area. The support area, which corresponds to the area required to balance the system of interest with the ELR of the region, was calculated as 27.2 km^2. This value is approximately 6 times lower than that calculated for renewable support, and this area may be used to predict short-term sustainability (Brown and Ulgiati, 2001).

SCS has one of the highest human development indexes of the country. This is directly associated to the prosperous industrial activity installed in the city.

The concept of carrying capacity appropriation is wider than the ecological footprint, because it depends on how it's defined the carrying capacity. Odum (1996) provides a clear definition to sustain a certain population (or in order to put a system in work) using only local renewable resources and also considering a certain development level.

Table 5 shows the carrying capacity appropriation ($CCA_{(r)}$) and overshoot considering the development model of SCS extended to the state of São Paulo and the country. The carrying capacity appropriation ($CCA_{(R)}$, in area) considering the state's renewable resources shows that if all São Paulo population consumed resources equivalent to those of the people in SCS, the state would have to count with an area 20 times higher. Even Brazil, with its large territory and high availability of local renewable resources, would have to triple its territory if Brazilian inhabitants consumed as much as SCS's population. In regard to the local conditions and the surrounding region's environmental stress ($CCA_{(ELR)}$), the F and N flows are substituted by R flows only till the limit they match the environmental loading ratio of the region. The support area would correspond to three São Paulo states or two countries, indicating that both the state and the country territories would be not enough to support their total population at the consumption levels of SCS.

CONCLUSION

An emergy synthesis of the urban structure of São Caetano do Sul was carried out, generating indicators of demand for environmental support and an overview on the primary inputs supporting the city. Comparison of calculated emergy indicators of SCS with those published for other cities provided an idea of their environmental/economic performance, confirming SCS to be a kind of emergy sink, but also ratifying its unsustainability, due to the excess reliance on non-renewable and external resources. It is clear that the urban structure only exists as part of a larger system represented in this work by the State of São Paulo and the country.

Using the indirect area concept to establish a relationship between the city and its surroundings authorizes to assign an adequate 'required' area in order to assure the needs for environmental resources. This required area would imbalance the relationship city/region, and its physical existence would secure the city sustainability, at least, for short-term. But it is important to keep in mind that a great disturbance will be created elsewhere as a consequence. For long-term sustainability, a larger area was calculated, and the establishment of this renewable support area should be considered as a fairest procedure to guarantee the urban center sustainability. Since cities are concentrated centers within the hierarchical spatial design, they use product flows concentrating consumption, money, information and play a decisive role in the spatial organization. However, for maximum performance, this central point must return services to reinforce the surrounding system.

The calculations performed correspond to extreme conditions both for support areas and carrying capacity appropriation, but give an idea of the limits that a system can succeed. It is worthy to note that cities also return waste materials released during the consumption process in dispersing pathways that make difficult to close the materials cycle essential to sustain production and the whole system. These calculations do not take into account the environmental services required to deal with the system's outputs (pollution, loss of biodiversity, et cetera). In this way, it is difficult to establish if these extreme

Table 5. Carrying capacity appropriation ($CCA_{(r)}$) and overshoot considering the development model of SCS

		Extended to	
	SCS	São Paulo State	Brazil
$CCA_{(R)}$ (m^2)	$9.14x10^{09}$	$4.92\ x10^{12}$	$2.40\ x10^{13}$
Overshoot (R)	609	20	3
$CCA_{(ELR)}$/(m^2)	$1.50\ x10^{07}$	$7.38\ x10^{11}$	$1.86\ x10^{13}$
$Overshoot_{(ELR)}$	1	3	2

values are under or overestimated. It is possible that the support area necessary to deal with the system's output be by itself much larger than those calculated in this work.

The origin of the inflows must also be determined, since a suitable policy for planning a system is to provide for materials to converge and diverge in complete cycles. Expenses on dispersing wastes back to the surrounding area may be as significant in the long run as those allocated to bring products into the centers of an urban center. The quality of inflows and outflows must be evaluated in order to eliminate or reduce waste, but also to refrain luxury reinforcing the flows that sustain productivity toward maximizing the system's performance.

Further work is needed to determine the real area required to maintain urban structures, which symbiotically act together with the surrounding area to maintain the production-consumption process. Among the main issues to be addressed, there are practical problems, such as the area required dealing with wastes and the area that can assure the arrangement for materials converge and diverge in order to approach a cycle virtually (or the maximum possible) closed. However, there are also ethical issues that must be dealt in the path towards sustainability, such as the quality and the utility of inflows and outflows.

ACKNOWLEDGEMENTS

Authors thank Vice Reitoria de Pós Graduação e Pesquisa of Paulista University for financial support.

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APPENDIX

Calculations of raw data presented in Table 2.

Item 1- Solar radiation:
Energy = (municipality area) x (avg. solar radiation) x (transf. cm^2 to m^2) (1-albedo) x (4186 J/ kcal)

$$\text{Energy} = (1.50\text{E+07m}^2)\times(1.32\text{E+02}\,\frac{\frac{\text{kcal}}{\text{cm}^2}}{\text{yr}})\times(1.00\text{E+04}\,\frac{\text{cm}^2}{\text{m}^2})\times(1\text{-}0.22)\times(4186\,\frac{\text{J}}{\text{kcal}}) \qquad \text{Energy} = 6.47\text{E+16}\,\frac{\text{J}}{\text{yr}}$$

Item 2- Rain chemical energy :
Energy = (city area) x (avg. rain fall discounted evap.) x (water density) x (Gibbs free energy)*
evaporation estimated in 20%

$$\text{Energy} = (1.50\text{E+07m}^2)\times(0.8\times3.1\frac{\text{m}}{\text{yr}})\times(1.00\text{E+03}\frac{\text{kg}}{\text{m}^3})\times(4.94\text{E+03}\frac{\text{J}}{\text{kg}}) \qquad \text{Energy} = 9.78\text{E+13}\frac{\text{J}}{\text{yr}}$$

Item 3- Rain geopotential energy:
Energy = (municipality area) x (avg. rain fall) x (run-off %) x (mean elevation) x (gravity acceleration)

$$\text{Energy} = (1.50\text{E+07m}^2)\times(3.1\frac{\text{m}}{\text{yr}})\times(0.64)\times(760\text{m})\times(9.8\frac{\text{m}}{\text{s}^2}) \qquad \text{Energy} = 1.84\text{E+14}\frac{\text{J}}{\text{yr}}$$

Item 4- Kinetic wind:
Energy = (municipality area) x (air density) x (drag coef.) x (speed^3) x (3.14 x 10^7 s/year)

$$Energy = (1.50E+07 m^2) \times (1.3 \frac{kg}{m^3}) \times (1.00E\text{-}03) \times ((3.6 \frac{m}{s})^3) \times (3.14E+07 \frac{s}{yr}) \qquad Energy = 2.86E+13 \frac{J}{yr}$$

Item 5- Geothermal heat: *Energy = (municipality area) x (deep heat flow)*)

$$Energy = (1.50E+07 m^2) \times (1.70E+06 \frac{\frac{J}{yr}}{m^2}) \qquad Energy = 2.55E+13 \frac{J}{yr}$$

Item 6- Fuels: *Energy = (consumption) x (heat power) x (4186 J/ kcal)*

Item 6a- Natural gas: $Energy = (2.29E+07 \frac{m^3}{yr}) \times (8800 \frac{kcal}{m^3}) \times (4186 \frac{J}{kcal}) \qquad Energy = 8.43E+14 \frac{J}{yr}$

Item 6b- Gasoline: $Energy = (4.65E+07 \frac{L}{yr}) \times (7844.2 \frac{kcal}{L}) \times (4186 \frac{J}{kcal}) \qquad Energy = 1.53E+15 \frac{J}{yr}$

Item 6c- Diesel: $Energy = (1.95E+07 \frac{L}{yr}) \times (8605.2 \frac{kcal}{L}) \times (4186 \frac{J}{kcal}) \qquad Energy = 7.04E+14 \frac{J}{yr}$

Item 6d- Sugarcane ethanol:

$$Energy = (1.95E+07 \frac{L}{yr}) \times (8605.2 \frac{kcal}{L}) \times (4186 \frac{J}{kcal}) \qquad Energy = 7.04E+14 \frac{J}{yr}$$

$$\text{Total energy of fuels} = 3.86E+15 \frac{J}{yr}$$

Item 7- Electricity: *Energy = (consumption) x (3.6 x 10^6 J/kWh)*

$$Energy = (6.33E+08 \frac{kWh}{yr}) \times (3.60E+06 \frac{J}{kWh}) \qquad Energy = 2.28+15 \frac{J}{yr}$$

Item 8- Treated water: *Energy = (avg. consumption per capita) x (1000 liters/m^3) x (365 days/ year) x (population*)

$$Energy = (2.38E+02 \frac{L}{day}) \times (1E\text{-}03 \frac{m^3}{L}) \times (365 \frac{days}{yr}) \times (1.52E+05\, inhab) \qquad Energy = 1.32E+07 \frac{m^3}{yr}$$

Item 9- Machines and equipments: *Value = (purchased value according to the SECEX Report)*

$$Value = 1.24E+08 \frac{USD}{yr}$$

Item 10- Energy of services: *Value = (purchased value according to the SECEX Report)*

$$Value = 3.87E+09 \frac{USD}{yr}$$

Item 11a- Food (services): *Value = (purchased value according to the SECEX Report)*

$$Value = 1.30E+07 \frac{USD}{yr}$$

Item 11b- Food:

Energy = (energy consumed by a human being per day) x (4186 J/ kcal) x (365 days/year) x (population)

$$Energy = (3.00E+03 \frac{kcal}{day}) \times (4186 \frac{J}{kcal}) \times (365 \frac{days}{yr}) \times (1.52E+05\, inhab) \qquad Energy = 6.97E+14 \frac{J}{yr}$$

Item 12- Chemicals: *Value = (purchased value according to the SECEX Report)*

$$Value = 1.29E+06 \frac{USD}{yr}$$

Item 13- Value of others imported: *Value = (purchased value according to the SECEX Report)*

$$Value = 8.90E+07 \frac{USD}{yr}$$