



# Conceptual Analysis on the Way Brazilian Cities Work: A Macroscopic View

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Cities play a crucial role in the development of nations, since they concentrate diverse forms of energy and transform them into higher quality outputs. An alternative for assessing urban agglomerates is the use of the eMergy synthesis method and the Odum's macroscope, which allow understanding and quantifying the energy flows that drive the cities functioning. The macroscope is able to identify the dependence relationships between cities and their surrounding environment that provides energy and resources to be transformed into high-quality products and information. After two decades of developing studies related to urban systems under Odum's macroscope approach, the research team of Paulista University in Brazil acquired experience and maturity to write this conceptual analysis about how Brazilian cities work. Several cases are provided—including anabolic and catabolic pathways involved in the regulation of cities mechanisms—to sustain final insights on the way Brazilian cities work. The results show how these cities add to the development the country transforming low quality energy into higher quality outputs. Cases are discussed under the Odum's macroscope perspective providing understanding on the dependence among cities and their neighborhood and helping to plan for future development.

**Keywords:** Brazil, cities, emergy synthesis, macroscope, sustainability

## INTRODUCTION

Cities play an important role in the development process of nations and are the places where people advance socially and economically. The United Nations sustainable development goal SDG 11 (Make cities and human settlements inclusive, safe, resilient, and sustainable) defines cities as nuclei of ideas, commerce, culture, science, production, and social development.

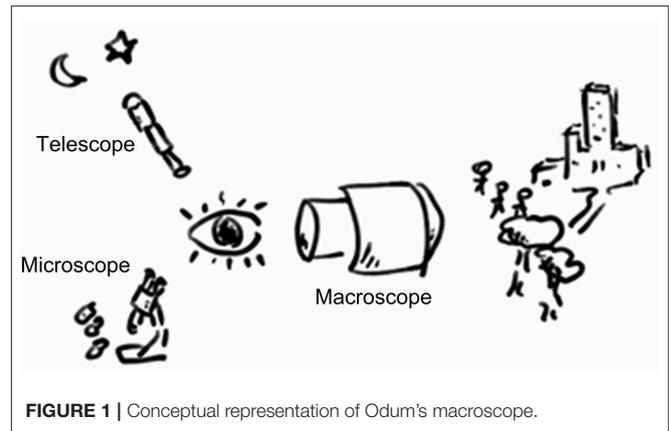
Emerging countries have experienced massive population migration from rural to urban areas in recent years. In Brazil, from 1960 to 2010, the percentage of urban population increased from 32 (45%) to 161 million inhabitants, 85% (IBGE, 2019). Under a sustainable perspective this growth, which occurred in a relatively short period, imposed obvious threats, and challenges to cities in providing adequate household facilities, proper water supplies, and sewage disposal, access to education, healthcare, and food supply. This growth has also aggravated socio-economic inequalities and the pressure on the surrounding environment that can be summarized by the food, energy, water nexus (FAO, 2014). Under the forecast that the world's urban population would grow by five billion people in 2030 (UN, 2016), Brazilian cities must be prepared for the SDG11's upcoming challenges creating jobs, preserving land and natural resources, reducing pollution, and improving the management of urban waste. These cities will also have to prepare to reduce poverty

allowing access of their entire population to basic services (energy, housing, and transportation). In face of these challenges, the efforts to achieve cities that are more sustainable are mandatory, and include the development of theoretical approaches that help to deal with urban metabolism and resilience and practical approaches that help to quantify the results of each action through the use of well-selected and representative performance indicators.

Cities can be understood as superorganisms that grow exchanging matter and energy with the external environment, processing resources, and generating waste (Zhang et al., 2009; Céspedes Restrepo and Morales-Pinzón, 2018). Under this concept, representing cities functioning, the term the urban metabolism approach (UM) proposes the study of cities considering the energy and material flows and the storage of assets that make the city superorganism operate synergistically. Among the studies on urban metabolism, progress was achieved mainly on methodological aspects, but there is still a lack of studies dealing with the socio-ecological issues that could support the design for sustainability. John et al. (2019) provided an analysis of the UM metaphor by describing the cities' dynamics, their interdependency, and the need for ecosystems to support their development. Through a literature review, Cui (2018) identified that research on cities' sustainability can be allocated into four clusters: conceptual analysis, metabolic indicators, circular use/management of materials and waste, and analysis of individual flows. This author emphasized that UM studies are vital to guide the development of urban sustainability in exposing new perspectives regarding urban development.

Several works associate sustainability and UM (364 peer-reviewed papers in scopus.com on October 3rd, 2019), and there are also those applied quantification methods to study part of the UM and its relation to cities' sustainability (Lei et al., 2008; Ascione et al., 2009; Sevegnani et al., 2017, 2018). However, attention was also called to the lack of studies combining social and environmental issues in regard to the improvement of life quality and welfare, instead of focusing exclusively on the maximization of energy (del Mar Martínez-Bravo et al., 2019; Ulgiati and Zucaro, 2019).

Evidencing the importance of cities in supporting the future societal development, the current scientific literature pays special attention to the cities' dependence on their surrounding natural environment. Cities are seen as open systems that respect the thermodynamic laws demanding resources and generating products and by-products (Pulselli et al., 2011). The understanding of the UM is fundamental for the elaboration of public policies that lead the actions toward more sustainable cities, and the evaluation of such complex systems demands conceptual models, which may provide different interpretation and cover different scales and purposes; see, for instance, MUSIASSEM (Giampietro et al., 2009), and FEW nexus (FAO, 2014). In this context, the macroscopic perspective might help to examine the complex system and its subsystems more comprehensively. According to Odum (1971), the macroscope can be understood as a tool capable of observing systems with a clear view of the parts by stepping back and simplifying complexity (Figure 1). Maud and Cevolatti (2004) described the



macroscope abilities in identifying the energy sources and flows, the transformations, the storages, and sinks. The identification of these elements that make up the complete system can help to recognize cause and consequence circuits. The macroscope can be used to observe systems that are too large, too slow, and too complex for the observer (Rosnay, 1979). An integral system's view can be provided by the macroscope, by drawing and connecting the systems' main parts to build more rigorous mental models and understand interdependencies. For these reasons, Odum's macroscope can be considered a suitable approach to assess cities, which are complex super systems/organisms that can hardly be fully understood under traditional and/or single perspectives. In regard to cities, the macroscope can provide information about the surrounding area supporting the cities' functioning and can offer a systemic perspective for understanding the relationships among suppliers, consumers, stocks, energy inflows, and outflows. For further reading, the special edition v.178 of *Ecological Modeling* "Through the macroscope: the legacy of H.T. Odum," published in 2004 and dedicated to Odum's scientific heritage is recommended.

Bearing in mind the world model provided by the macroscope, H.T. Odum believed that to ensure a prosperous future, humanity would have to develop partnerships with nature (Campbell, 2004). Humanity must find ways to synergistically coexist with nature rather than use it as a source of infinite resources and infinite capacity to absorb waste. Natural systems self-organize, and Odum (1996) expanded the maximum power principle to the maximum eMpower principle, by stating that all self-organizing systems that tend to maximize their emergy use, or empower, will prevail (Li et al., 2013). To maximize their emergy use, the energy used by human systems may be appropriately matched with energies used/provided by the natural systems to maximize empower (Brown et al., 2004; Campbell, 2004), strengthening the link between humankind and nature. Cai et al. (2004) stated that the maximum empower principle can explain the ever-present hierarchical self-organization process observed in all natural and socioeconomic systems.

Brown et al. (2004) highlighted the importance in understanding how systems change, grow, die, react to disturbances, or reorganize to accommodate new conditions.

Policymaking driven by qualitative guesses must be replaced by policymaking based on quantitative predictions based on scientific models. This concern could be alleviated with the use of the Odum's macroscope, which can help to understand complex systems and to formulate strategies for managing societal development under ecosystems constraints. The macroscope can also help to grasp the nature and man-nature interactions and the prevalence of energy relations, and emergy synthesis, based upon the macroscope view, reduces ecosystems complexity to manageable dimensions.

Emergy is the available energy of one kind of previously used up directly and indirectly to make a service or product. Emergy synthesis and its indicators can be seen as a tool to quantify and help us to understand the better choices for the partnership between man and nature (Campbell, 2004), i.e., how man's economic system can be optimally coupled with the free work of nature. The most powerful characteristics of emergy synthesis is its ability to recognize and compare energy of different quality (Brown et al., 2004), resulting in an objective value-quantifying method that allows ranking the influence/effect of all the flows that come from the natural environment, using a common unit (sej; Odum, 1996). This hierarchy of energy flows proposed by Howard Odum's self-organization and transformation concepts was empirically confirmed by Giannetti et al. (2019). For further details regarding theory, concepts, meanings, and procedures supporting emergy synthesis, please refer to Odum (1996).

This work presents several examples on the use of the Odum's macroscope to understand complex urban systems in terms of resource use and sustainability. Under the eMerger theory, the research team of Production and Environment Laboratory (LaProMA), Paulista University, Brazil, has been performing urban systems-related research for 20 years, acquiring experience and maturity to generate this conceptual analysis on how cities work, using Brazilian cities as case studies. The analysis is organized into the cities' anabolic and catabolic activities providing insights on the behavior of cities. As part of the urban metabolism analogy, the "anabolism" and "catabolism" are used herein to represent, respectively, the "creation" of complex high-quality products and the "dismantling" of complex structures into simpler ones.

## ANABOLISM: CONSTRUCTIVE ACTIVITY

### Finding Social Housing Projects With Higher Emergy Performance

The Brazilian federal government established standardized social housing projects as a means to provide shelter for low-income families. The existing projects are named popular housing (R1), popular building (PP4), and building of social interest (PIS). Low-interest bank loans to constructors and families are available, as well as tax reduction during and after the construction phase.

Brazil is a large country with different biomes, cultures, climate conditions, and with the different spatial distribution of construction materials availability. Although the standardized social housing projects were derived from an important policy

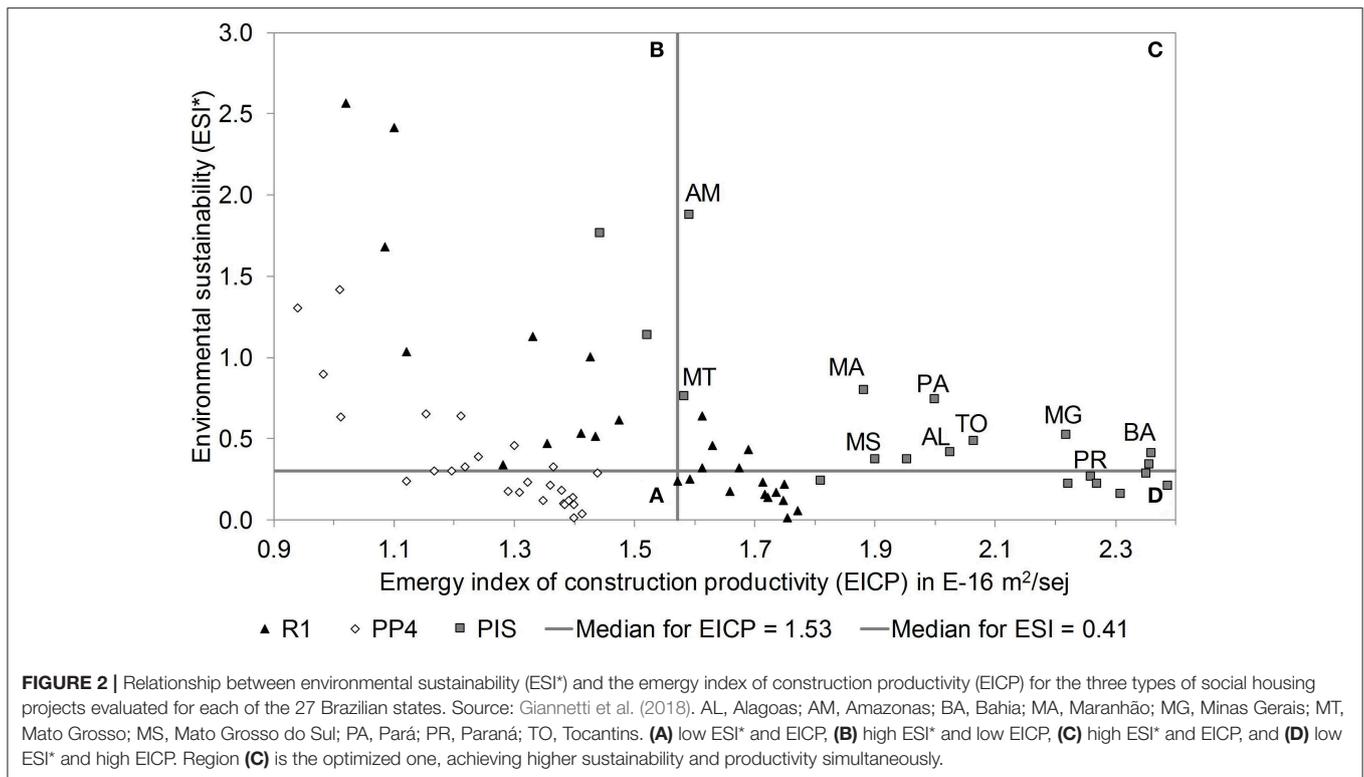
under social perspective, their application across the country raises doubts about the implementation of one type of project over another in the different states toward a better environmental performance. In this sense, Giannetti et al. (2018) studied the Brazilian social housing projects aiming to determine which project is the most adequate to be implemented in each one of the 27 Brazilian states. Using emergy synthesis, the authors accounted for the resource exchanges among the Brazilian states classifying them into renewable, non-renewable, or imported from other states. Focus was also given in the partial renewability of some resources used during housing construction.

The results, analyzed through the emergy ternary diagram, showed that although the R1 project obtained higher performance for the environmental sustainability index (ESI\*) in most states, all three projects are strongly more dependent on non-renewable resources (*N*, local free resources from nature) than on the imported (Imp) and on renewable (*R*) ones. Complementarily, results were presented in a graph (Figure 2) relating the ESI\* with the emergy index for construction productivity (EICP, in m<sup>2</sup>/sej), which supports a holistic (Odum's macroscope) decision on what type of social housing project should be supported in each Brazilian state to achieve higher sustainability. Results indicated that PIS should be implemented in 21 states, while R1 in 6. Popular building (PP4) should not be implemented in any state based on the emergy environmental perspective.

The large Brazilian territory and its regional specificities (cultural, climatic, socio-economical), the individual access of each State to energy and material resources make this kind of evaluation an important example in showing that projects (including social-housing ones) should be carefully chosen by considering environmental variables. Standardizing projects or even choosing projects exclusively based on economic and/or social concerns could be premature, since the opportunity to maximize sustainability could be either forgotten or neglected.

### Capital Stocks for Three Cities of Great São Paulo: Santo André, São Caetano do Sul, and São Bernardo do Campo

Sevegnani et al. (2018) assessed the internal stocks of an urban system comprising three municipalities in São Paulo, Brazil, called ABC Paulista. The macroscope allowed to visualize the urban stocks that were classified as economic, natural, and social capitals. The economic capital was identified as built structures and vehicle fleet. The natural capital is composed of the water from the reservoirs and the biomass, while the social capital regards the population. The three forms of capital combine themselves promoting development, growth, and complexity. The emergy of natural capital can be understood as a measure of the cities' reliance on natural resources. Less than 1% of the relative participation of ecosystem goods and services was observed, indicating that the ABC Paulista, like other urban centers, sustained its growth based on economic and social capitals, putting aside the preservation of green areas, and local resources. Results also revealed that economic capital is greater than the social one. Due to its high industrial activity, ABC



Paulista can be seen as an “urban industry,” when viewed under the macroscope. Raw materials are transformed into final goods using know-how, as well as the infrastructure, justifying such a large economic capital portion. The “urban industry” activities contribute to the development of the larger system (State and Nation), however, as a counterpart, they are highly dependent on external resources and environmental services.

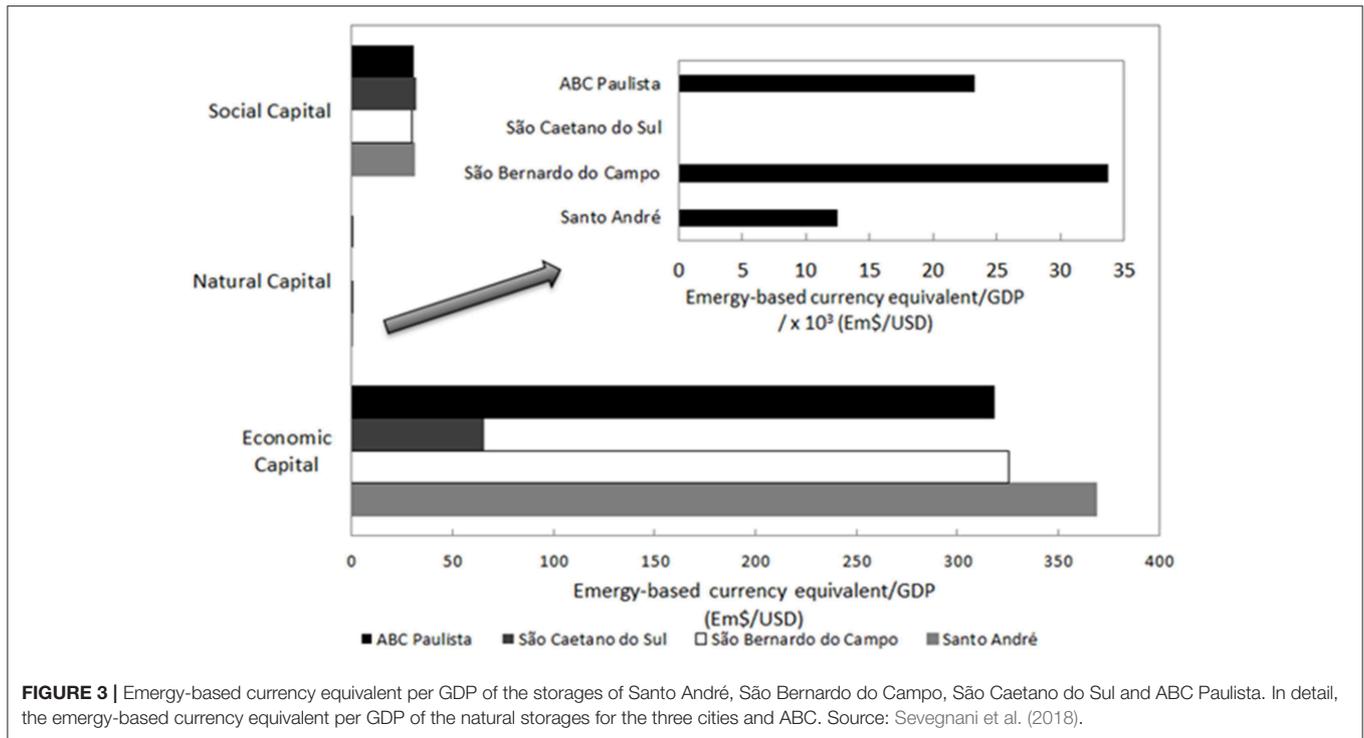
The natural and economic storages of assets were assessed, generating the value of each capital in emergy units (sej) transformed into “Emdollars,” using the eMergy-based currency (Figure 3). The bars show the capital needed to generate one unit of GDP, or the capital available for a GDP unit in each urban system. Estimations can be made in terms of total exploitation of one stock and the effects this would cause, as well as whatever effects the increment of one stock would generate.

The results showed an approximate relation of 12,000:1,100:1 for economic, social, and natural capital respectively. ABC Paulista needs more than 300 dollars of capital (in terms of stock) to make 1 dollar circulate in the economy, confirming that this urban system requires much more feedback from the economy than from local resources, renewable or otherwise, leading to an interpretation of non-sustainable systems. On the other hand, it is possible to identify that part of the emergy of this urban system is used to develop and maintain high-quality assets, giving support to activities that generate higher energy content (transformity) goods and services. The macroscopic view can identify that stored energy is used to increase the size and complexity of the system, and the assessment of storages can help to understand and measure the system complexity.

## Trade and Prosperity of ABC Region: Santo André, São Caetano do Sul and São Bernardo do Campo

Emergy accounting was also used to study the ABC Paulista under the perspective of prosperity, carrying capacity, and trade (Sevegnani et al., 2017). Accounting for 0.5% of total national emergy, ABC Paulista works as a production center combining the abundance of labor and knowledge with the proximity to large consumer centers.

The emergy indices (Table 1) revealed unsurprising results, enforcing the idea of high dependence of the urban systems on external resources, from both inside and outside Brazil. Approximately 50% of the total emergy of ABC Paulista results from foreign imports and the remaining 50% is from internal (Brazil) imports. The main internal imports are electricity and fuels. The value of Emergy Yield Ratio (EYR), very close to 1 (one), indicates that this urban system is a simple consumer system showing no ability to rely solely on its local resources. On the other hand, the high value of the Environmental Loading Ratio (ELR) shows that the activities occurring in ABC cause high environmental stress. Dividing the EYR by the ELR gives the Environmental Sustainability Index (ESI), which is also low, thus evidencing the environmental pressure resultant from an economy that is highly dependent on imported resources, underlining a low contribution of local resources to the growth of the GDP. Under the light of Emergy Accounting, this urban system can be classified as non-sustainable, since it presents low environmental yield and high environmental loading.



**TABLE 1 |** Emery indices of ABC and the three municipalities.

Indicator	ABC	A	B	C
Environmental Loading Ratio (ELR)	362	466	260	2078
Emery Yield Ratio (EYR)	1.003	1.002	1.004	1.000
Emery Sustainability Index (ESI)	0.003	0.002	0.004	<0.001

Where: Santo André (A), São Bernardo do Campo (B), and São Caetano do Sul (C).

Source: Sevegnani et al. (2017)

A carrying capacity evaluation was performed and revealed that ABC would support only 4,500 people when considering reliance only on its renewable emery sources, which corresponds to 2% of the actual population.

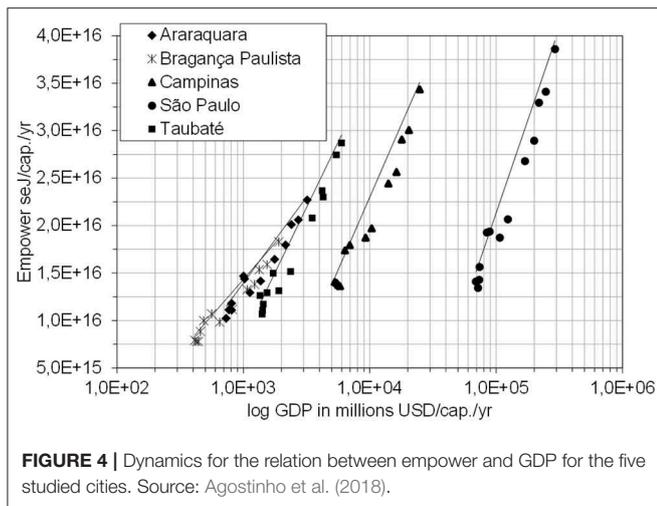
The fairness of the trading activities was evaluated by the emery exchange ratio (EER) indicator. The emery benefit ratio value for ABC was 2.3, when trading with foreign countries and 1.7 when trading internally with the rest of Brazil. This indicates that when ABC trades with foreign countries, its exports aggregate 2.3 times more emery in goods and services than ABC receives from the money paid for these exports. Trading internally with Brazilian regions is less disadvantageous (EER = 1.7). So, the trading activities with Brazil and foreign countries are disadvantageous for ABC, and all its municipalities. These results contradict the traditional monetary approach showing that ABC exports, despite promoting economic growth, deliver much more emery to the buyers than the emery received back in currency units. The conclusion is that ABC Paulista works primarily as an “industry” and not as a municipality, allowing to suggest that, in the short term, reducing exports to foreign

countries and increasing trade with Brazil should attenuate the losses in emery terms and could establish a fairer trade activity.

## Searching Indications for the Limits of Cities Growth

Under the Club of Rome’s idea of limits to growth, and recognizing the exponential increase of world population migrating from rural to urban areas, studying the cities limits to growth is of paramount importance to subsidize public policies toward sustainable development. This is especially true, since cities are mostly dependent on fossil energy and other non-renewable materials to support growth. Policymakers must understand the limits of urban growth before proposing the most appropriated policies for sustainable growth. In this context, Agostinho et al. (2018) applied emery synthesis (Odum’s macroscope) in five cities (Araraquara, Bragança Paulista, Campinas, São Paulo, and Taubaté) located in São Paulo State, Brazil, in an attempt to quantify their limits to growth. Emery was used as a proxy to visualize the limit to growth, specifically calculating the dynamics of empower per capita (in sej/capita/yr) and emery to money ratio (EMR, in sej/USD) from 1999 to 2011.

The obtained empower and EMR dynamics showed similar growth behavior for all evaluated cities but indicated different development growth stages for each city. Improved efficiency was also observed for all cities, which means that they are able to generate a dollar to GDP by demanding a lower amount of emery. As represented in **Figure 4**, stabilization of cities’ empower per capita and/or of GDP was not observed, maybe because the limits to growth had not yet been reached within the time period considered. Since the evaluated cities are



representative for São Paulo State, the state with the highest social-economic performance among the Brazilian States, it is expected that obtained results can be applied for all other Brazilian cities, each one under its own development stage.

This work also contributed to the advances of emery synthesis by suggesting the use of thermal transfer in estimating the rainfall transformity (14,150 se/J) rather than the traditional approach considering chemical and/or potential rainfall energy, and that index of sustainable economic well-being (ISEW) should be used instead of total GDP to better represent the monetary contribution for societal well-being.

## Support and Regulating Services of 73 Urban Parks in São Paulo City

The ecosystem services provided by urban parks were the object of the study by Almeida et al. (2018a). The evaluation was done using the emery synthesis applied to 73 parks spread throughout the city of São Paulo, Brazil. The parks were divided into small, medium and large and the indicators used for the assessment were the emery of the NPP, emery of evapotranspiration, emery of water retention, as well as the Global Productivity (GP) of CO<sub>2</sub> sequestration, evapotranspiration, and water retention. **Figure 5** shows a summarized emery diagram that can be constructed when using Odum's macroscope. The system receives renewable natural resources (R) and purchased resources (F) from outside its boundaries. These resources, combined with the non-renewable resources (N) inside the system, give support to the NPP stock and help to maintain the facilities inside the parks. The yield of the system presented on the right side of the diagram is the benefits provided to the larger system—the city of São Paulo.

Comparisons of each indicator per area of each park were made, and the results revealed that the most important service provided by the urban parks is the CO<sub>2</sub> sequestration, represented in **Figure 5** by the storage of net primary production (NPP). Results revealed that parks with less than 10,000 m<sup>2</sup> generate ecosystem services less efficiently and the larger ones

tend to require less energy. The study estimated the emery value of the ecosystem services provided by the parks as Em\$ 8.5 million and the cost for the municipality as Em\$ 6.4 million. Thus, for each Em\$ invested in the 73 urban parks of São Paulo, a Em\$1.33 return to the municipality is achieved, indicating a positive benefit/cost ratio. It was concluded that decisions on the implementation of new parks or the renovation of the existing ones should consider trade-offs between maintenance costs and the value of the main ecosystem services provided/desired.

In that same year, Almeida et al. (2018b) evaluated how the ecosystem services provided by the urban parks are provided and used, at different spatial scales. The evaluation of environmental costs and the monetary costs determined what type of park is more adequate and meets the environmental needs of a given surrounding neighborhood.

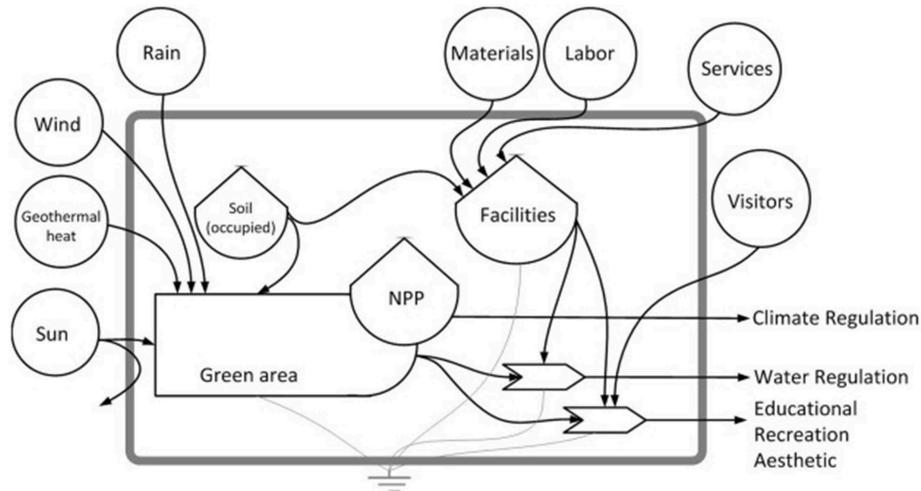
The ratio between natural and economic resources was used as an indicator to manage the urban parks allowing to identify the best configuration for each one, as well as actions for future developments, and the adjustment regarding housekeeping for the existing parks. The results showed that in São Paulo, when considering the total number of small parks, the delivery of ecosystems' services is insufficient, when contrasted with the economic investment made by the municipality. This statement shows a different position when comparing to studies that report higher benefits of implementation of a great quantity of small parks when comparing to fewer ones occupying larger areas. The study calculations show that 82 new small parks would be required in São Paulo city, for the whole set to reach the natural/economic balance. These new parks should consider a tree/grass relationship of 80:20. It was also found that only larger parks (larger than 250,000 m<sup>2</sup>) are beneficial in terms of climate regulation.

## CATABOLISM: DESTRUCTIVE ACTIVITY

### Assessing the Efficiency of Recycling Urban Solid Waste in a Treatment Plant

Although allowing for a fast growth on a series of desired socio-economic aspects, urban agglomeration also results in a series of undesired or "catabolic" activities, such as highly concentrated urban solid waste (USW) generation that must be collected, transported and treated appropriately. Urban waste management is of utmost importance due to its direct related social and environmental risks (bad odor, bad landscape appearance, proliferation of disease vectors, toxicological issues on water, and soil, global warming gases emissions, risks on regional fauna, etc.), as well as the indirect associated costs. All this becomes even worse in a city with 12 million inhabitants concentrated in a 1,500 km<sup>2</sup> area.

Alternatives to manage USW are needed, mainly those most sustainable-oriented. Under this scenario, a sorting and composting waste treatment plant (SCWTP) was proposed and implemented in São Paulo city, and its efficiency was assessed under a macroscale perspective (emery synthesis) by Agostinho et al. (2013). The obtained results emphasize that, while for some materials (iron & steel, plastic, and compost)



**FIGURE 5** | Energy system diagram of an urban park. NPP: net primary production. Source: Almeida et al. (2018a).

the recycling process is advantageous under a net energy yield perspective, for others (glass and aluminum), the energy invested is higher than the energy received back with recycling. Only through a macroscope perspective as represented by **Figure 6**, one can visualize the energy flows supporting the SCWTP, and understand the reasons why not every recycling processes can be considered as a better alternative for urban waste management. The so-called hidden costs that are not usually perceived under smaller-scale analyses can be identified and accounted for in energy synthesis. Several external resources are used by internal processes, which results in different performance levels for the recycled products.

Although not showing a positive energy yield for some recycled materials, the evaluated SCWTP is still a better alternative than sanitary landfill (with and without electricity generation by burning methane) when compared with data from the scientific literature. The importance of the macroscope in the work of Agostinho et al. (2013) sustains that such conclusions can be only achieved when this larger-scale perspective is applied, avoiding decisions based exclusively on economic aspects.

## Assessing Technological Options for a More Sustainable Urban Solid Waste Treatment

Frimaio (2017) assessed technological options for more sustainable treatment of urban solid waste including landfill, incineration, plasma arc, composting, and pyrolysis. Plant scenarios were proposed to indicate the best option for megacities, medium, and big-sized cities, spatially distributed in each region in Brazil. Odum's macroscope (emergy synthesis) and goal programming were used as scientific methods. The proposed scenarios considered the efficiency of waste treatment options as well as the resulting benefits that each technology could provide, such as electric power and/or organic compost.

Results show the treatment option that integrates incineration and composting with a 50% share for the organic fraction of urban solid waste, demands the lowest amount of resources (emergy) for every city-size within the Brazilian regions. It was realized that it is more advantageous (i.e., lowest demand for non-renewable energy) to increase the percentage of organic matter to 100% in the incineration-composting technology than using any other treatment option, since energy per mass of treated waste will be still lower.

Although Odum's macroscope provides an important perspective for a decision, sometimes the cultural, economic, and geographical aspects do not allow for a decision based exclusively on emergy, which claims for a methodological approach that is able to find the best single technological waste treatment option when more drivers are taken into account. This is primarily important for decision-makers, who demand this kind of information from the scientific arena. In so doing, establishing and using a goal-programming model including the variables costs, emissions, energy, treatment time, and area, the optimized result indicates the following order of preference for waste treatment option: composting, incineration, landfill, plasma arc. This is valid for all municipality sizes and their location, as well as for all different organic fractions in the waste.

## Assessing Treatment Processes for Domestic Wastewater

Giannetti et al. (2016) assessed domestic wastewater treatment processes, in order to identify priority actions toward an improvement on sustainability performance. Odum's macroscope (emergy synthesis) was used as a method in quantifying the sustainability for two domestic wastewater treatment processes: activated sludge and biodigester. The costs supported by the surrounding environment to dilute the concentrated wastewater was the focus, as well as the demand for resources to implement and operate each treatment process. Emergy synthesis numbers were converted into land-area in an

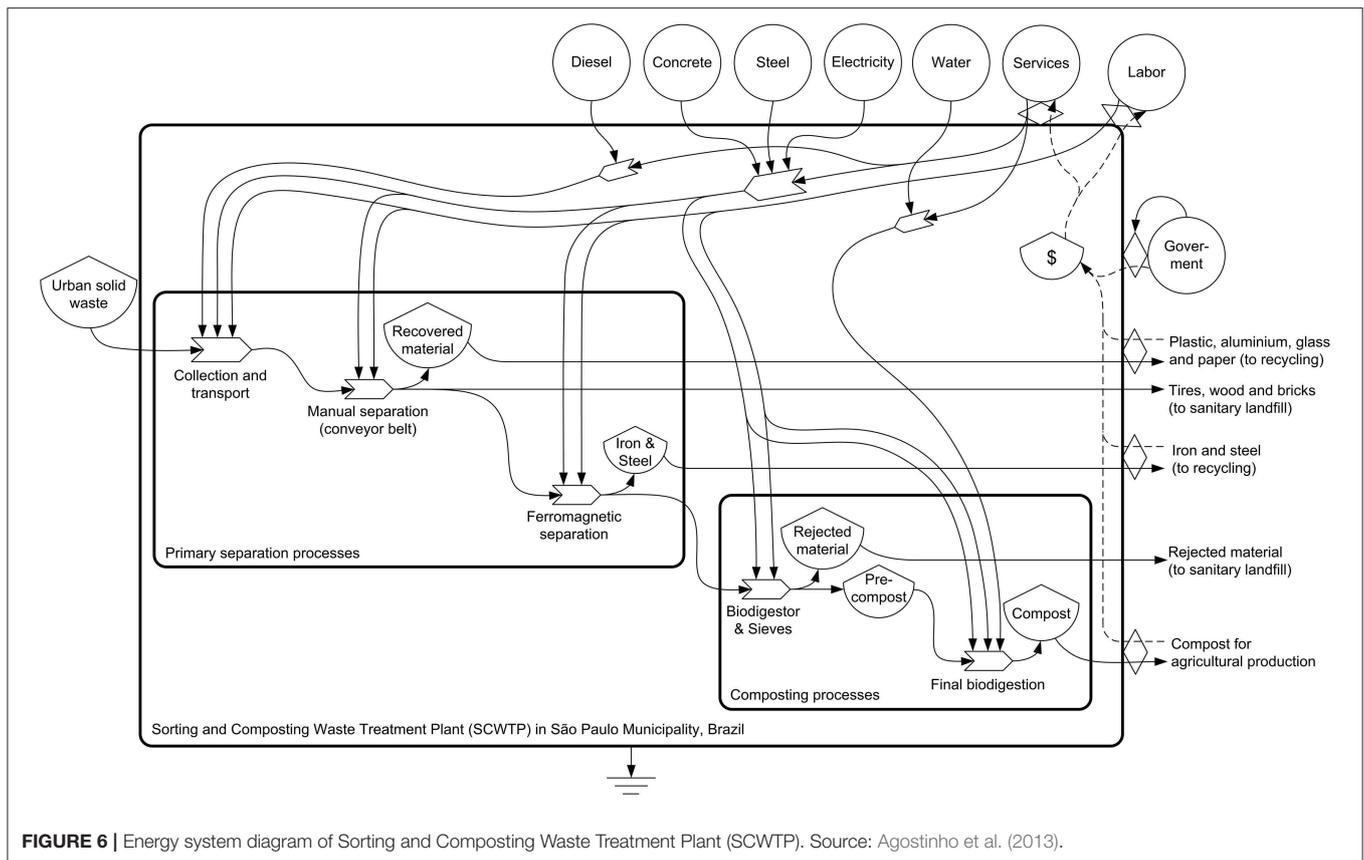


FIGURE 6 | Energy system diagram of Sorting and Composting Waste Treatment Plant (SCWTP). Source: Agostinho et al. (2013).

TABLE 2 | Carrying capacity for the two evaluated domestic wastewater treatment options.

Indicator	Activated sludge (m <sup>2</sup> /m <sup>3</sup> )	Biodigester (m <sup>2</sup> /m <sup>3</sup> )
Direct area	0.0027	0.0018
Modified ecological footprint	1.1615	0.2778
Support area	11.3465	0.0002
Support renewable area	2.6360	0.6858
Re-irradiation area	90693.1	220.1

Upstream and downstream environmental services are considered. Values refer to 1 m<sup>3</sup> of wastewater. Source: Giannetti et al. (2016).

attempt to represent the support area for each treatment process that could be useful when deciding upon the location to install wastewater treatment plants.

Results show that the main resource inputs, in terms of energy, for the activated sludge are electricity (28%) and labor (17%). For the biodigester, 44% of its emergy is related to labor. An important finding is that, during the operation phase, the biodigester requires only 20% of the emergy required by the activated sludge plant; the biodigester is the lesser resource-demanding option. When it comes to pollutant dilution, the environmental services of dilution required by the active sludge system correspond to 27% of its total emergy budget, which is high when compared to the 1% required by the biodigester. Another result that can show the high impact

of the activated sludge system is that the emergy investment to dilute the emissions would be 60,000 times higher than that of the biodigester when comparing equal volumes of treated wastewater.

Although aiming at the same ultimate goal (i.e., to treat domestic wastewater) of helping the natural environment deal with the waste of human activities, both evaluated technological options impose a degree of additional load on the environment, by demanding resources for their implementation and operation phases. Usually, this can be observed and understood only by considering a macroscope perspective. Thus, the choice between one of these two treatments should consider the extent of the imposed extra environmental load due to the use of the ecosystem services required to dilute their emissions and the availability of an environmental support area to supply the resources required to their operation. Results showed that the biodigester option has better performance for all aerial-based indicators (Table 2) than the activated sludge option to treat the same volume of wastewater.

## WHY BRAZILIAN CITIES ARE THE WAY THEY ARE: AN ODUM'S MACROSCOPE PERSPECTIVE

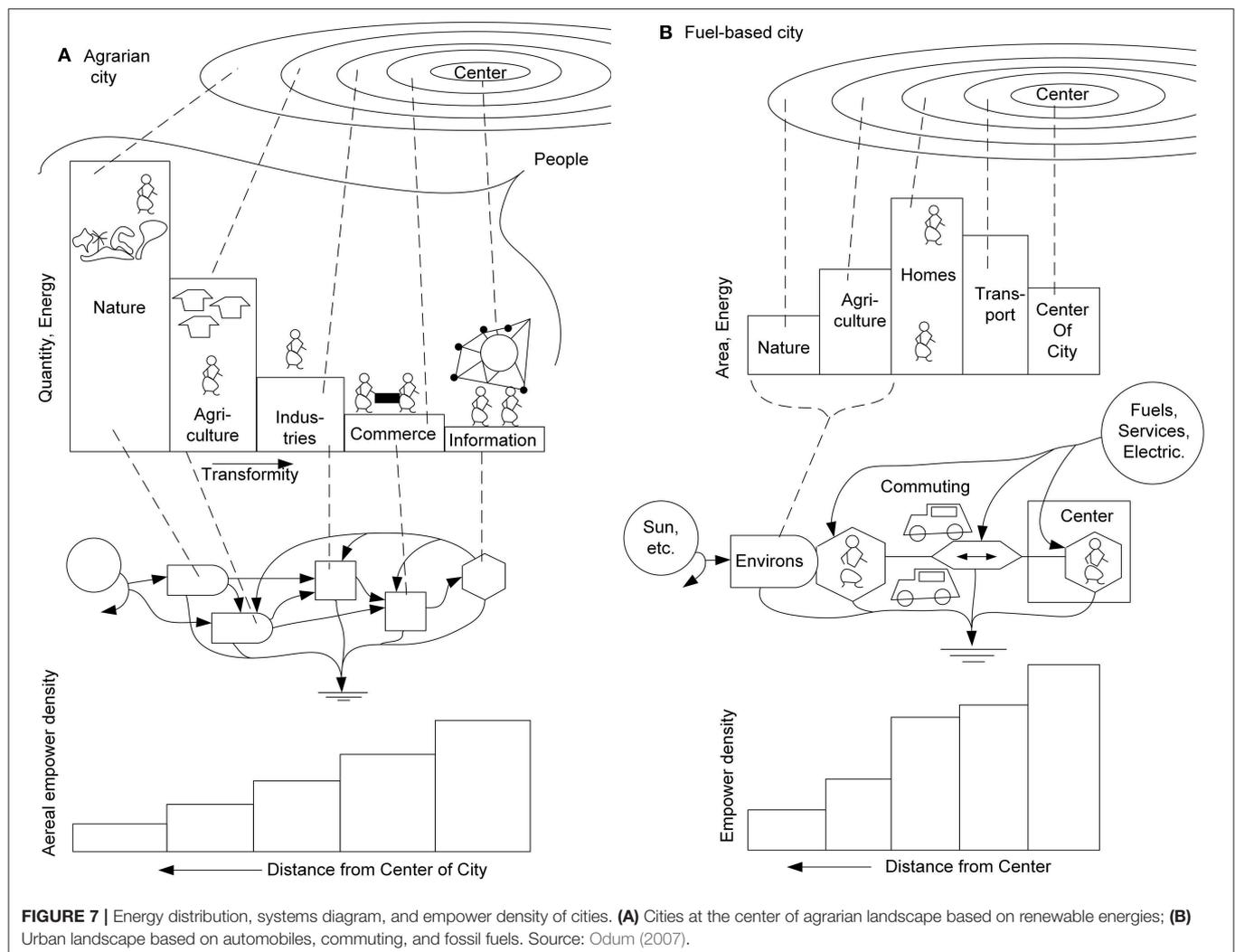
According to Odum (1996), cities are self-organized systems aiming to optimize their efficiency in the conversion of input

energy into the output of goods and services in accordance with the maximum empower principle and adapting according to the surrounding environment that supplies energy and resources. Under the macroscope perspective, Odum (2007) presented an urban landscape model for an agrarian and fuel-based city (Figure 7). Human societies have moved from agrarian regions to urbanized centers that contain large energy storages, high activity, and high-quality work (high transformities). Differently from the agrarian landscapes that converge energy from rural sources to support their cities, the fuel-based cities of the twenty-first century directly receive the concentrated fossil energy to support their development (Odum, 2007).

According to the case studies presented in this conceptual analysis article, Odum's macroscope can be recognized as an important approach to verify the relationship among cities and their surrounding environment, identifying the main flows of energy supporting cities development, and the self-organizing nature of socio-economic (urban) systems. The self-organization was clearly perceived in some

of the cases presented in this work, including the ABC municipalities, the social-housing projects, and the search for the cities' growth limits, figuring examples of systems that tend to maximize their rate of energy use (maximizing empower) to prevail. Differences among the Brazilian cities' development were identified and attributed not only to the diversity of cultural and economic factors, but mainly to their natural surroundings (biocapacity). In this sense, it was shown that standard actions could be premature, even if socially or economically effective, if they disregard environmental concerns.

The case of ABC cities showed that the trade-off of energy flows (mostly fossil-based ones) is intense among these cities and with the surrounding environment, confirming the urgent need for policies that give support to citizens who currently live in an urban industry, where the largest capital is composed by built structures and vehicle fleet in detriment of the natural capital. The study of the balance among the social, economic and environmental capitals (and the contribution from each one) would help



policymakers understand the structure that holds each city and the actions required to make cities friendlier to their inhabitants.

The study of the cities' subsystems (including urban parks, water treatment plants, and solid waste management) using the macroscope helped to give support to decision-makers to identify the relationships among these subsystems and the city. The information provided allows to identify the actual benefits and the desired or undesired trade-offs supporting decisions (in terms of emergy).

The search for sustainable development must take into account material welfare and happiness. With this in mind, it can be argued that the macroscope perspective in assessing how cities work is important to provide insights on alternatives in converting energy flows into quality of life for citizens. The experience of the Paulista University research group, obtained throughout the last two decades, shows that the macroscope diagnosis is a fundamental step to support specific-oriented public policies toward efficient and sustainable development for cities. Cities depend on the use of external resources such as fuels, minerals, electric power, goods, and services generated from these resources (**Figure 8**), public policies may allow these resources to synergistically interact with each other, maximizing empower. Hopefully, the proper synergistic interactions would allow an urban qualitative growth in happiness, quality of jobs, citizen security, and sense of community, while detrimental drains, such as accidents, crime, and pollution should be reduced.

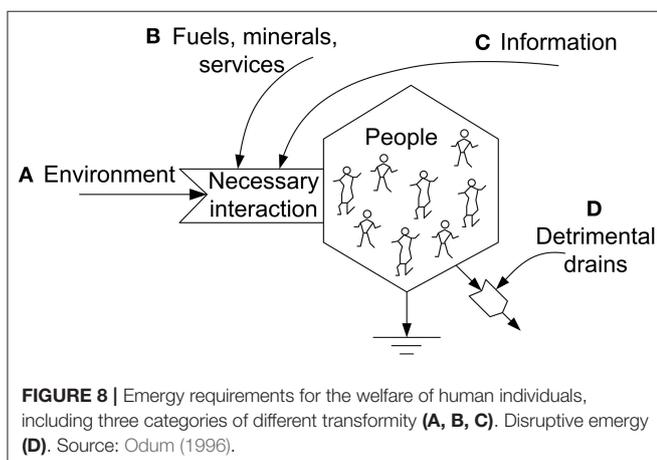
Emphasizing the fundamental role of cities in the development of countries as accountable to converge and transform energy into higher quality outputs, this work presented cases and discussed about Odum's macroscope, and provided understanding on the energy flows driving cities. The authors hope that the examples provided can support insights upon the contribution of the emergy view to identify the relationship of dependence among cities and their surrounding environment, thus helping policy and decision making on cities future planning and development.

According to Odum (2007), while people were migrating to the cities, fossil fuels were cheap. The psychological need for

green spaces (ecosystems) by people working in the centers caused pathological overuse of automobiles in cities. The simple design of people living as part of the central structure was displaced by suburban living and commuting. Individuals sought individual cars for their freedom, their powered access to ecosystems, and the time they saved. The city was transformed by the great emphasis on transportation devoted to the oscillation of automobile people in and out. Individual cars and the highways to support the daily shuttle took over the city organization, destroying neighborhoods, and causing slums to develop, with a large waste of emergy. It is urgent to plan for smaller cities with fewer cars, greater agricultural activities within these cities and, consequently, fewer problems with pollution. There is also a call for the possibility of planning to move the population from city areas to agricultural towns. Somehow similar behavior can be observed, for example, in big cities, where a great part of the workers lives in the smaller surrounding cities and commute to the bigger city (Odum et al., 1995), denoting that the surrounding cities may offer higher levels of livability.

Due to the peak oil production and climate change concerns, it is more and more evidenced that humans must reduce their demand for fossil energy while simultaneously looking for alternative renewable sources. For such an important goal, a macro-perspective approach is essential to support further micro-specific oriented public policies. The relationship between universities as research centers and policymakers must be strengthened to allow a large divulgation of scientific findings in a more popular language to sustain policy propositions. This is mainly true in Brazil, since the governors and policymakers that are chosen democratically to represent the society desires hardly ever take scientific findings into consideration. The reason for such behavior must be better understood. Although Brazil has important federal laws on guidelines for urban public policies (e.g., law no. 10257/2001), these can be considered superficial and lacking in operability, because they only provide general ideas toward sustainable, more democratic, cooperative, and inclusive urban agglomerates. This must be improved, since the policymakers are in charge of converting those general ideas into more practical and specific-oriented actions. With all this in mind, it can be argued that both perspectives, macro and micro, in assessing how cities work are important to guarantee sustainable development. Both can provide important insights into converting energy flows into quality of life for citizens. SDG #11 is an excellent example of an oriented policy that provides specific targets to be achieved by cities until 2030.

Complementary to the insights derived from emergy synthesis, the fossil-carbon emission is a current worldwide problem. The Intergovernmental Panel on Climate Change (IPCC) periodically publishes the so-called assessment reports, however, through the last two decades, cities have received lower attention—or not viewed as a system in its totality—than other “categories” in the IPCC reports, such as energy systems, buildings, agriculture, transport, industries, and forestry. However, the IPCC announces a special report exclusively focused on Cities for the Assessment Report 7. In this context, it is possible to notice that studies related to sustainability of urban systems at any scale of attention



(macro and microscales, upstream and downstream focus, etc.) are growing more and more in importance, receiving attention due to high potential risks to people—keeping in mind that 50% of global population lives in cities—in a scenario where a strategic planning based on scientific-based diagnostics are missing. This is particularly important in Brazil due to its large territory (8,511,000 km<sup>2</sup>) that encompasses 5,570 municipalities.

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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