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URBAN INDICATORS AND PLAN TO IMPROVE URBAN SUSTAINABILITY: THE CASE OF SAO PAULO CITY

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ABSTRACT

Sustainable city is a city with characteristics that allow the improvement of population´s quality of life without destroying the natural resources available on it. Improve sustainability should be the goal of every government in charge of a city. The first step a public administrator should do is to define areas to focus on. Then, he should select indicators to measure the urban conditions and evaluate some aspects of the city. This work has the objective to discuss the concepts of urban indicators for sustainable cities and conduct a case study for the city of Sao Paulo, Brazil, analyzing its actual situation in terms of urbanization and the impact son the city environmental conditions. The city has geographically grown indiscriminately in the last years, with low investments in public transportation. The fleet of cars increased a lot, causing congestion in its streets. With more cars on the streets, the air quality of the city remains not good, away from international acceptable standards. We are going to propose measures to improve the city sustainability, through investments in its urban infrastructure, especially transportation. The conclusions show that the disordered growth of the city is related to the worsening of its sustainable situation.

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INTRODUCTION

The increasing and accelerated processes of urbanization have worries public managers, citizens, and companies. The United Nations estimates that 70% of the world's population will live in cities by 2050 (UN, 2018b). This fact brings innumerous challenges to cities, such as pollution, traffic jams, etc. But before analyzing the problems a city faces, it is necessary to select the problems to be treated and evaluate the dimension of these problems, otherwise we will be working in the dark, fighting an enemy we cannot even see. That is the reason we use models and tools to measure how smart are the initiatives proposed and carried out by a city to solve its problems (Al-Nasrawi *et al.,* 2015). These models and tools are composed by indicators, sometimes grouped in categories, used to measure the performance of a city, make a diagnosis of its current situation and help to establish a plan to improve its sustainability. We are going to use the DEQ (Diesel Emissions Quantifier) tool from the EPA (United States Environmental Protection Agency) to estimate the effect of a specific measure to promote sustainability in urban environments. In this paper we are going to analyze the city of Sao Paulo. With approximately 12 million inhabitants, the city of Sao Paulo is the 4th megacity in the world in terms of population (UN, 2018a) and the main city of Brazil. Fifteen technical indicators were selected from two different indexes to assess the sustainability of Sao Paulo. These indicators are from two groups, urban development and environmental conditions. Series of data were collected and are presented here to evaluate the current situation of the city and the evolution during the last years. Then, the causes of these values are discussed and a set of policies and measures to improve the city sustainability is proposed. Finally, the DEQ tool was applied to estimate the effect of one of the measures proposed to promote sustainability in the city.

The accelerated increase of the city population over the last 70 years, multiplying its inhabitants by almost 6 (IBGE, 2017), has led to innumerous problems like inefficiency of public services, precarious health conditions, rationing of water resources, among others. Therefore, the goal of this work is to evaluate investments in urban transportation and its impact on the quality of life of the inhabitants of a city. This will be achieved through the measurement of renew urban buses in the city of Sao Paulo, for a generic bus corridor, and the impacts in emissions that would improve air quality and generate cost effectiveness. This paper is structured in five sections. This introductory section presents the general idea of the work and the goal defined. Next section, literature review, defines some important concepts used here. Then, material and methods section explains briefly the case study methodology, which is the methodological approach used on this paper. On results section, technical indicators selected to analyze the city of Sao Paulo are presented with historical data and discussions about them are made. Proposals to improve the city sustainability and the application of the DEQ tool are presented in discussion section. Finally, the conclusions section closes the paper.

Literature Review

To develop this work in an appropriate way, it is necessary first to define some concepts that will be applied to the case study in the results section. Therefore, this section presents definitions for sustainable cities, indicators and urban sustainability indicators.

Sustainable Cities

When a city grows, its population begins to affect the environment and the natural functioning of its ecosystem. Castells (2000) states that a city can be defined as sustainable if its conditions of production and operation do not destroy its own conditions of expansion over time. In other words, a sustainable city is a city where its resources are available for the population use to improve its quality of life, without causing damage to the environment. These resources can be traffic and public transportation systems, energy, security systems and civil defense, services to the population, water supply and sewer treatment, health infrastructure, technologies of information and communication and Internet, for example. And the improvement in the population´s quality of life generates impacts on income, employment, services and happiness.

Indicators

Indicators are key components of measurement. Measurement, in turn, is a prerequisite for improving systems (Lawlor, 1985), like cities. In addition, indicators are an integral part of the management process, being used in important activities of this process such as planning, problem solving, decision-making, improvement, control, among others. Besides that, it is argued that one cannot manage what one cannot control and that without a performance measurement process; it is not possible to know if the system is consistently improving (Sink and Tuttle, 1989). Radnor and Barnes (2007) state that: measuring the right things and using these indicators are the basis of improvement; developing a manageable and coherent set of indicators, rather than a hodgepodge of disconnected measures for activities, is a challenge; another challenge is to develop forecasting tools; and the public sector must learn to adapt – not merely adopt – and apply the most effective experiences available.

Urban sustainability indicators

There are many city indicators and city indexes, like the City Prosperity Index – CPI (CPI, 2018) and the Global Power City Index – GPCI (MMF, 2018). These indicators can be used both to monitor the conditions of the urban environment, to point out trends and draw attention to weaknesses, and as an auxiliary tool in the planning process, enabling the definition of scenarios, setting goals and prioritizing actions. Lumbreras (2018) presents a list of other measurement models and its foci:

- Global Competitiveness Index: microeconomic and macroeconomic foundations;
- Network Readiness Index: market conditions and connectivity status;
- ICT Development Index: ICT developments;
- Global Innovation Index: role of science, technology and innovation;
- E-government Development Index: willingness and capacity to use ICTs to deliver public services;
- Green City Index: environmental performance and policies;
- Digital Economy Ranking: ICT to be used for economic and social benefit;
- Change Readiness Index: policies and capacities that should facilitate healthy, dynamic and responsive markets;
- Better Life Index: people´s well-being and societal progress;
- Cities in Motion Index: driving forces to have a good performance;
- SDG Index: seventeen sustainable development goals;
- ISO 37120: standardization of indicators.

The problem is that there is not like a universal set of indicators and the disaggregation is different in each case. Who intend to select and use a group of indicators to analyze a city should decide first what is the purpose of the work. With this in mind, then is possible to start selecting indicators to compound a unique index directly related to the goal established to be achieved.

MATERIAL AND METHODS

This section describes the scientific method used to achieve the objective proposed in this work and explains the reasons that led the researcher to choose one path over another, presenting elements that justify this choice. The research method, from the epistemological point of view, comprises a set of rules that ensure that the steps to obtain the desired results are fulfilled. Thus, the procedures for planning and carrying out the research are defined and justified. We adopted a qualitative method to carry on this research. A feature of qualitative research is that it occurs in its natural environment, where the researcher conducts the work in order to delve deeper into the study (Creswell, 2018). Due to the qualitative nature of this research, where it is sought to deepen the knowledge of a certain phenomenon, the case study becomes an applicable method, since it intensively examines the object of study (Yin, 2014). By adopting collection techniques and data analysis procedures, it is possible for the researcher to deepen the understanding of the research object. As a research strategy, the case study allows, objectively, to understand the behavior of a phenomenon given a given context, through the analysis of a case. In this way, the research will be carried out in the city of Sao Paulo to study its urban development and environmental conditions. Specifically, for this subject, we selected some technical indicators from 2 different indexes to assess the sustainability of the city. Then a series of data were collected and are presented in the next section to evaluate the current situation of the city and its evolution during the last years. These values are discussed on the next section. On the discussion section, we used the DEQ (Diesel Emissions Quantifier) tool to assess one project proposed to improve sustainability in the city of Sao Paulo. The tool, developed and offered by EPA (United States Environmental Protection Agency), provides an interactive web-based platform for users, evaluates clean diesel projects and upgrade options for medium-heavy and heavy-heavy duty diesel engines and estimates baseline emissions, reduced emissions, cost effectiveness for NOx, PM2.5, HC, CO and CO2, and PM-related health benefits.

RESULTS

The Case of Sao Paulo

Brazil is an antagonistic country. At the same time, it can be considered highly sustainable in some criteria, due to its enormous natural reserves, such as the Amazon rainforest and its enormous water potential; the high level of poverty, the numerous health problems and the high level of social inequality, make the country not so sustainable. Sao Paulo, the city chosen to this study, is the most populous city in Brazil and the 4th largest city by population in the world with 12 million inhabitants (IBGE, 2017, UN, 2018a).

Sao Paulo

The city of Sao Paulo has the 10th largest GDP in the world, representing alone 13% of all Brazilian GDP (IBGE, 2017). When compared to countries, Sao Paulo city alone would have ranked 26th in GDP total. But, at the same time, the city who owns the biggest population of helicopters in the world (even greater than NYC) and offers opportunities to work for lots of Brazilians from all over the country, has more than 700,000 people, or 6% of the population, living in extreme poverty with less than USD 1.90 per day. Its growth rate between the years 2000 and 2010 was 0.6% a year, and despite the decline in population growth over the last decade, the high population pressure and accelerated urbanization were unplanned. The increase of the city population over the last 70 years, multiplying its inhabitants by almost 6, has led to innumerous problems like inefficiency of public services, pollution, traffic jams, precarious health conditions, rationing of water resources, social inequality, among others. Health and safety are, respectively, the first and second major problems of Sao Paulo, in the evaluation of its inhabitants. For 38% of city residents, services such as hospitals are the main reason for dissatisfaction. For 14%, violence and crime are the worst flaw in the city (FSP, 2016).

Urban Indicators for Sao Paulo

Fifteen technical indicators were selected to assess the sustainability of the city of Sao Paulo. Once the objective of this work was to evaluate the urban development and the environment conditions of the city, the indicators were selected with this goal in mind from to 2 indexes, the City Prosperity Index – CPI (CPI, 2018) and the Global Power City Index – GPCI (MMF, 2018). The indicators were grouped in 2 categories: urban development and environmental conditions. The list is presented below with the conceptual basis for each one: indicator group and index. The general indicators are the only ones not related to any group from an index. But, once they provide a broad vision of what has happened to the city in the last years, we considered them important to compose the set of indicators.

General:

- Population Growth;
- Urbanized Area.

Urban Development:

- Fleet of Cars (Urban Mobility – CPI);
- Congestion Index (Urban Mobility – CPI and Environment – GPCI);
- Use of Active Transport Modes (Urban Mobility – CPI);
- Use of Public Transportation (Urban Mobility – CPI and Environment – GPCI);
- Traffic Deaths (Urban Mobility – CPI);
- Housing Units for Social Use (Housing Infrastructure – CPI);
- Reduction of Floodable Areas (Water and Energy – CPI and Environment – GPCI).

Environmental Conditions:

- Plant Cover Index (Environment – GPCI);
- Number of Fall Trees (Environment – GPCI);
- Air Quality PM 2.5 (Air Quality – CPI and Environment – GPCI);
- General Air Quality (Air Quality – CPI and Environment – GPCI);
- Rain (Water and Energy – CPI and Environment – GPCI);
- Waste Sent to Landfills (Environment – GPCI).

In the next sections, we are going to present the general data and the 15 technical urban indicators with the data collected for Sao Paulo, from different sources, and explain the values and its causes of variations.

Population Growth

The population growth rate of Sao Paulo between the years 2000 and 2010 was 0.6% a year, and despite the decline in population growth over the last decade, the high population pressure and accelerated urbanization were unplanned. Table 1 presents the population numbers for the city. The increase of the city population over the last 70 years, multiplying its inhabitants by almost 6, has led to innumerous problems like inefficiency of public services, pollution, traffic jams, precarious health conditions, rationing of water resources, social inequality, among others.

Urbanized Area

The urbanized area of the city has also significantly grown in the direction of the peripherical portion of the city, as it is possible to see in Figures 1 and 2. Figure 1 presents the situation of grow from 1950 until 1962, and then from 1963 to 1974.

Table 1. Population growth for Sao Paulo. Source: IBGE, 2017

Census	Population	Increase
1872	31,385	
1890	64,934	106.90%
1900	239,620	269.00%
1920	579,033	141.60%
1940	1,326,261	129.00%
1950	2,198,096	65.70%
1960	2,781,446	26.50%
1970	5,924,615	113.00%
1980	8,493,226	43.40%
1991	9,646,185	13.60%
2000	10,434,252	8.20%
2010	11,244,369	7.80%
Est. 2018	12,176,866	7.70%

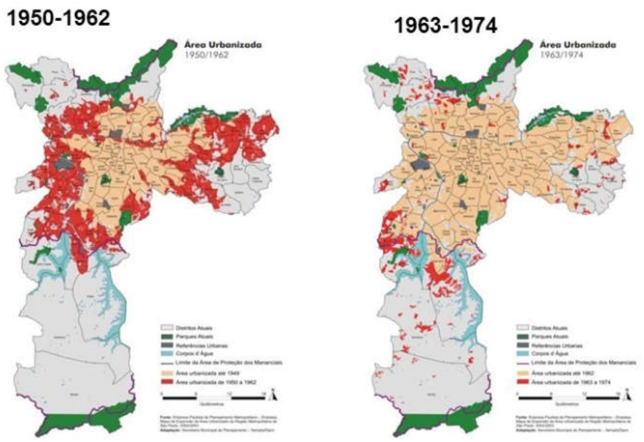

Figure 1. Sao Paulo Urbanized Area. Source: SMU, 2017

Figure 2 presents the evolution of the urbanized area from the center of the city, in dark blue color, with urbanization until 1891, to the dark red in the periphery, with urbanization from 1993 until 2002. It is possible to see that the vegetation areas in the city, marked in green, are in the periphery and are very scarce in the city.

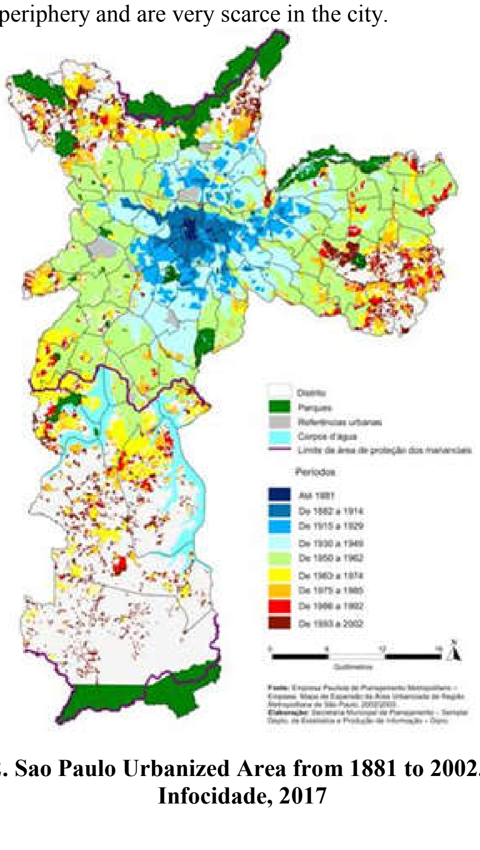

Figure 2. Sao Paulo Urbanized Area from 1881 to 2002. Source: Infocidade, 2017

Fleet of Cars

As we saw, Sao Paulo is a very big city and the public transportation is not so extensive and good. This leads people to buy cars and, in most of the time, drive it alone. As we can see on Table 2, the fleet of cars for Sao Paulo was more than 6 million on 2017.

Table 2. Fleet of Cars for Sao Paulo. Source: DETRAN-SP, 2018

Year	Fleet of Cars (millions)
2010	5.09
2011	5.21
2012	5.31
2013	5.44
2014	5.63
2015	5.78
2016	5.91
2017	6.05

This number has increased almost by 1 million cars from 2010 to 2017. An increase of 19% in just seven years.

Congestion Index

With so many cars on the streets, congestions are inevitable. They are part of the life of who lives in the city. Figure 3 presents the number of kilometers of congestion in the city in 3 different periods of the day. The upper curve presents the afternoon peak (5pm until 8pm), the middle curve presents data for the morning peak (7am until 10am) and the lower curve shows the between peaks congestion volume (10:30am until 4:30pm).

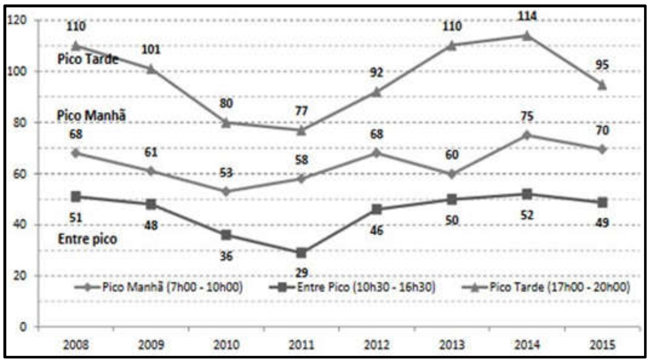

Figure 3. Sao Paulo Congestion Volume. Source: CET, 2018

The valley between 2009 and 2013 is due to the global financial crisis that the city and the country also faced, after 2008.

Use of Active Transport Modes

Active transport methods are defined as the non-motorized travel modes, like walking, cycling, skateboarding and others. In a research conducted in 2017 by the City of Sao Paulo (PSP, 2017), 39.48% of interviewed people goes by bus; 36.06% on foot; 10.04% by subway; 6.17% on his own private car; 5.70% by train; 1.03% by motorcycle; 0.63% by taxi or application; 0.48% use bike or skateboard or other non-motorized modes; 0.28% use motorized bicycle or other motorized modes and 0.13% chartered buses. Therefore, for the PSP (2017), the indicator of use of active transport modes is 36.54% for 2017, unfortunately the only year with available data.

Use of Public Transportation

The use of public transportation is directly related to the decrease of the congestion index in any city. The majority of vehicles circulating in Sao Paulo is autos. The idea with this indicator is to measure and encourage the use of public transportation in the city. In 2016 the average number of kilometers per inhabitant, traveled using public transportation, was 2,653 (PSP, 2017). This is the only available data for this indicator in PSP (2017).

Traffic Deaths

The most terrible indicator of problems with traffic in a city is the number of traffic deaths. Figure 4 presents the numbers for Sao Paulo from 2005 until 2016. Although the number decreased 43% in 11 years, it is still high with 854 deaths occurred in traffic accidents in 2016 (DETRAN-SP, 2018).

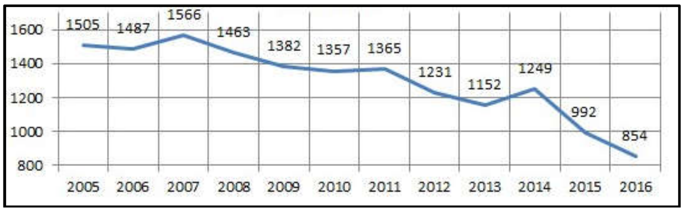

Figure 4. Sao Paulo Traffic Deaths. Source: DETRAN-SP, 2018

Housing Units for Social Use

The idea with this indicator is to measure the number of houses delivered for homeless people in order to take them out of the streets. This indicator measures the social availability of house infrastructure to the neediest. In 2017, 4,800 houses were delivered to the population (PSP, 2017). This is the only available data for this indicator in PSP (2017).

Reduction of Floodable Areas

The low amount of permeable areas in the city of Sao Paulo increases the total flooded area of the city. In 2016, this area was 22.5 km2 and in 2017 it was 21 km2 (PSP, 2017). This can be explained by the increase of trees in the city or due to the weather conditions, with less rain in the last year of the research.

Plant Cover Index

Figure 5 shows the Plant Cover Index (PCI) per region of the city of Sao Paulo (Buckeridge, 2015). The regions highlighted in black has a PCI of less than 8.4, considered a low index. These are regions of high priority, where it is necessary to have challenging goals to increase the number of trees. The red regions are medium priority with a PCI from 8.5 to 13, where it is also necessary to have a more intensive action in order to improve the presence of trees. The blue regions are regions of secondary priority with PCIs varying from 13.1 to 22.5. In these regions, it is necessary to maintain and replace some trees. Buckeridge (2015) considers PCIs above 35 as high. While some more peripherical regions have high PCI values, clearly affected by forest residues or state parks near the city, certain regions of the metropolis do not have that much influence.

Number of Fall Trees

Sao Paulo has a falling rate of 0.5% trees per year, for the total number of trees in the city. For 2016, this means 3,231 trees (EBC, 2017; Veja, 2017). Since 2011, this number has grown more than 55%, with just one year of decrease that was 2013, probably due to a very prolonged drought that occurred in the city, causing less rain than the historical average. Table 3 presents the number of falling trees from 2011 until 2016.

Air Quality PM 2.5

In Sao Paulo, the mobile and fixed sources of pollution were responsible for the emission to the atmosphere of approximately 131 thousand t / year of carbon monoxide, 38 thousand t / year of hydrocarbons, 80 thousand t / year of nitrogen oxides, 5.1 thousand t / year of particulate matter and 6.7 thousand t / year of sulfur oxides. Of these totals, motor vehicles account for 97% of CO emissions, 76% of HC, 68% of NOx, 17% of SOx and 40% of MP (CETESB, 2017).

Although the size of the fleet of gasoline vehicles is smaller than that of the fleet of flex-fuel vehicles (gasoline and ethanol), emissions from this first segment are higher because of the higher average age of gasoline vehicles. The motorcycle segment, even with a smaller fleet, also has a significant participation in CO and HC emissions (18% and 8%, respectively). Despite that, the news is not so good, the air pollution particulates per cubic meter is over twice what is deemed safe by the World Health Organization (WHO). For the entity, a city can only be considered with clean air if it presents an average of 10 micrograms of PM 2.5 per cubic meter (WHO, 2016). Any value above poses a health risk. PM 2.5 are air pollutants with a diameter of 2.5 micrometers or less, these particles generally come from activities that burn fossil fuels, such as traffic, smelting, and metal processing. For São Paulo, the rate was 19 micrograms of PM 2.5 per cubic meter in 2016 (RSDC, 2017).

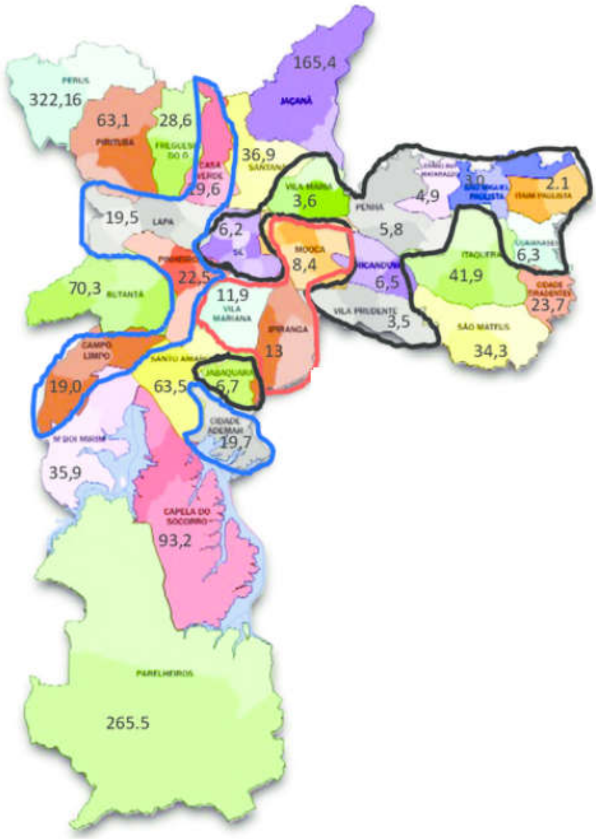

Figure 5. PCI per Region of Sao Paulo. Source: Buckeridge, 2015

Figure 6 presents the values of PM 2.5 for Sao Paulo since 2000 in the green line. The red one presents the reference value based on WHO.

Table 3. Fall Trees in Sao Paulo. Source: EBC, 2017 and Veja, 2017

Year	Fall Trees
2011	2,080
2012	2,497
2013	1,861
2014	2,282
2015	2,894
2016	3,231

It is possible to see that the best value for Sao Paulo was in 2009, 15 micrograms per cubic meter, 50% worse than the reference value. A specific pollutant that is as source of concern in Sao Paulo is the nitrogen dioxide (NO2), a toxic reddish-brown gas that is a strong oxidizing agent, produced by combustion as of fossil fuels, according to Merriam-Webster (2017). In 2015, the value was 199 micrograms / m³, against a WHO reference value of 40 (RSDC, 2017). The sulfur dioxide (SO2), a heavy pungent toxic gas that is easily condensed to a colorless liquid, is used especially in making sulfuric acid, in bleaching, as a preservative, and as a refrigerant (Meriam-Webster, 2017). It is another pollutant of main concern for the city, found especially in industries.

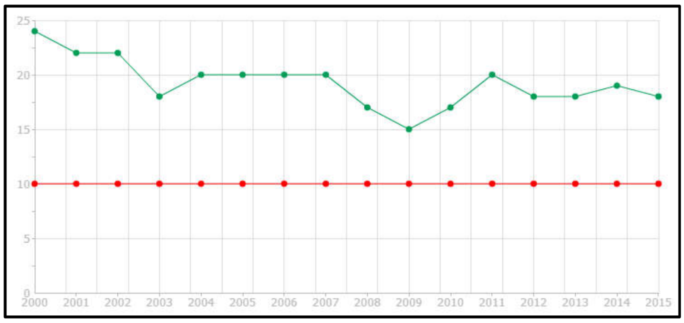

Figure 6. Values of PM 2.5 for Sao Paulo. Source: RSDC, 2017.

General Air Quality

The general air quality indicator is an index evaluated from the environmental company of the State of Sao Paulo. It is possible to check the air quality in lots of different measurement stations of the city and the results indicate if the air quality is adequate, moderate or inadequate. At the moment of the measure showed in the Figure 7, the air quality was considered of moderate quality with a value of 43 and highlighted in yellow in a specific station (CETESB, 2017).

Rain

The volume of rain is increasing year by year, with some small variation. Due to the natural seasonality it is possible to see in the Figure 8 the variation in annual volume of water in millimeters. The line represents the average value of the period. During the period evaluated the volume of rain increased 43% in volume of water (CETESB, 2017).

Waste Sent to Landfills

Sao Paulo still send a huge amount of garbage to landfills. Other options for the adequate and sustainable destination of the waste generated by the population are available in some specific regions in the city, but its use is not yet fully available to the entire population. In 2013 the volume of waste sent to landfills was 15,405,000 tons. For 2016 the number remained almost the same with 15.562.000 tons (PSP, 2017).

DISCUSSION

Improvement Plan for Sao Paulo

This section presents a sustainability improvement plan for Sao Paulo focusing on its public transportation. The first section will present the plan with its policies and measures. Then, on the second section, one specific project, the renew of the buses of one corridor will have its impacts calculated using the DEQ tool from EPA.

Policies and Measures

As we have seen, the city of Sao Paulo has grown a lot and indiscriminately in the last years, with low investment in public transportation, causing the fleet of cars to increase a lot. This has led to more traffic. With more cars on the streets, the air quality of the city remains below international standards. Once it is not possible for the municipal government to make inhabitants change their cars for less pollution ones using alternatives sources of fuel, like electrical cars; the government should invest in public transportation. With a good quality system, people will let their cars in their homes and use public alternatives. Sao Paulo has a not so broad metro network in the city. The costs for implementation are high and the lines construction

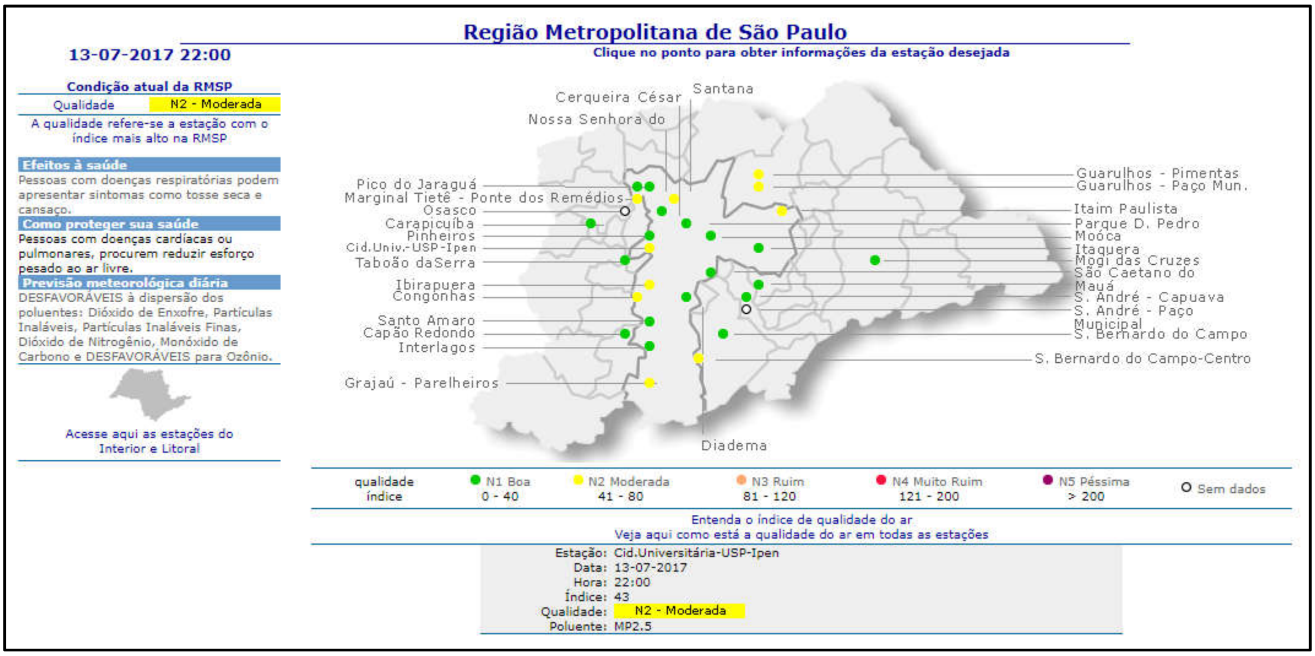

Figure 7. Air Quality of Sao Paulo. Source: CETESB, 2017

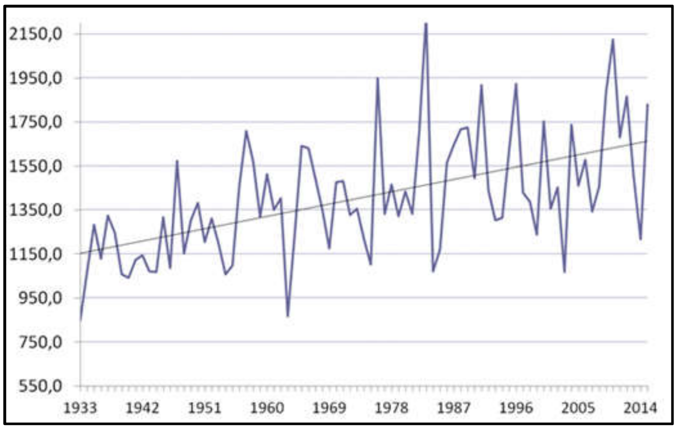

Figure 8.Volume of Precipitation in Sao Paulo. Source: CETESB, 2017

impacts a lot the city. On the other hand, according the CET (2018) and DETRAN-SP (2018), the city has 1,339 lines of buses served by 14,452 buses. The system has also 238 kilometers of bus corridors, that are part of the streets for the exclusive use of the buses, allowing them to run in a more fast and constant speed. These specific lanes let the system more reliable, making the inhabitants know when the bus will arrive to the bus stop and when they will arrive on their final destination. In 2017, the city of Sao Paulo structured a program with goals to be achieved until 2020, called "Programa de Metas 2017 – 2020". This program presents lots of initiatives to be conducted in 4 year in the city (PSP, 2017). They are grouped in 5 specific areas:

- Social Development;
- Human Development;
- Urban and Environmental Development;
- Economic and Management Development;
- Institutional Development.

In the Urban and Environmental Development area, there are some measures defined from the government, regarding the public transportation of the city.

Measure 1

The first measure is to reduce in 15% the emissions of CO_2, in 50% the emissions of PM2.5 and in 40% the emissions of NOx by the bus fleet of the city until 2020. The baseline values for this goal are from 2016. Once the CO_2 emissions on that year were 1,044,332 tons, the PM2.5 were 74 tons and the NOx were 4,999 tons; the reduction to be obtained are 156,649 tons for CO_2, 37 tons for PM2.5 and 1,999 for NOx. The CO_2 and NOx emissions are directly related to the fleet fuel consumption.

Measure 2

The second measure proposed is to carry out safety assessment and, promote adequacy of geometry and signaling in eight corridors of public transport to improve safety conditions. The objective with this measure is to reduce the number of deaths in traffic for a value of less than 6 for each 100 thousand inhabitants until 2020. As we have seen in 2016 the total number of deaths in traffic in the city were 854, which means 7 deaths for each 100 thousand inhabitants. This reduction, if achieved, will mean 14% less death in the traffic of Sao Paulo.

Measure 3

Measure 3 consists in building and putting in operation 72 kilometers of bus corridors. Here the indicator is the extension of bus corridors built and delivered to operation.
Currently, São Paulo has approximately 238 km of bus corridors. In addition, there are 28 municipal and 1 inter municipal bus terminals. The objective here is to implement infrastructure projects of public transportation road system for the flow and integration of the various modalities to promote safe, fast, accessible and sustainable inter modality. It is hoped, that good service quality will be offered to the population, contemplating speed, comfort, punctuality, regularity, security, tariff modality, efficiency, respect for the principles of sustainability, technological relevance and universal accessibility, particularly for people with physical or sensory disabilities and reduced mobility, the elderly and pregnant.

Measure 4

Increase by 7% the use of public transport is the forth measure proposed. And this measure is related to the action proposed in the measure above. The indicator of public transport used for this measure is the sum of the number of passengers multiplied by the extension, in kilometers, of each of the three transportation systems in place in the city (municipal buses, subway trains and subway) weighted by the resident population in Sao Paulo. This number was 2,653 in 2016 and the target for 2020 is 2,840.

Estimation of the Effect of a Measure using DEQ Tool

To address the public transportation situation of the city, improve its quality and reduce the emissions generated, the costs for the population and the deaths caused in the traffic; the city of Sao Paulo published a public bidding notice (PSP, 2018). The scope of this bidding was the operation of the buses of the city, which is considered the largest in Latin America. The new contracts signed were expected to promote the renovation of the 14,452 buses that operated in the city, as it prohibited the circulation of vehicles with more than 10 years and the obligation to keep the average age of the fleet to 5 years, including cleaner models drive by natural gas, biomethane and electric or hybrid propulsion. With the duration of 20 years, the total value of the contracts was estimated to be USD 17.8 billion. There were 3 types of operational sub-systems (PSP, 2018):

- The structural, operated by larger buses, such as the back and low floor, articulated, super-articulated and bi-articulated buses, which travel through large avenues, high traffic streets and through corridors that make the connections between the terminals, passing through the center city;
- The regional articulation, new in the city and that functions as an intermediary system, linking more distant neighborhoods to regional centers (without passing through the city center) by means of basic buses, with front engine;
- The local distribution subsystem, operated by smaller vehicles between districts and terminals, bus corridors and subway stations and urban trains. Mini-buses, midi (microns) are the standard type provided for this system, depending on the road conditions.

In order to estimate the impact of this important project from the municipal government, we chose the DEQ (Diesel Emissions Quantifier) tool from the EPA (United States Environmental Protection Agency). This web-based tool evaluates clean diesel projects estimating baseline and reduced emissions of NOx, PM2.5, HC, CO and CO2, cost effectiveness and also PM-related health benefits (EPA, 2018). Once the tool offers the possibility to evaluate at the same time reduced emissions, cost effectiveness and health benefits, we considered DEQ the most adequate tool to evaluate this project. The tool is available at the website of EPA and a researcher interested on using the tool, just have to make a login with minimal personal information to have access. Figure 9, below, presents the main screen of the tool.

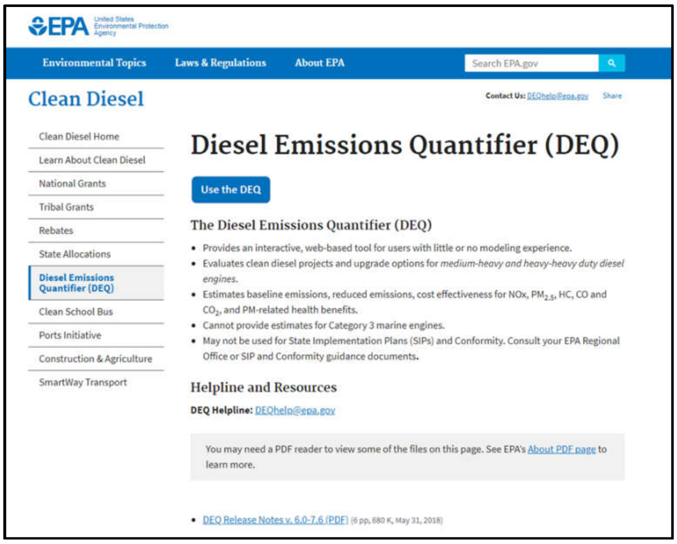

Figure 9. DEQ Tool Main Screen. Source: EPA, 2018

With the objective to estimate the impact of an action related to measure number 3, renew bus corridors, in measure number 1, reduction of emission; we chose one generic corridor to make a pilot project. The corridor was estimated to have 15 kilometers, with 30 different lines, each one with 10 bus. So, we made a pilot with 300 buses and a total implementation cost of USD 350,000,000.00. These values are in line with the bidding the government of Sao Paulo ran in 2018 and with the fleet of buses and kilometers of corridors the city had, as presented above. In this project, called New Bus Corridor, we simulated 3 different modifications in our generic actual corridor:

- The implementation of diesel oxidation catalyst in the whole fleet, at a cost of USD 2,000 for each bus (material and labor);
- The implementation of diesel particulate filter in the whole fleet at a cost of USD 2,000 for each bus (material and labor);
- The change of fuel from biodiesel 5 to biodiesel 20 with no extra cost.

Figure 10, below, presents the scope of the project analyzed with the tool.

Group Name: New Bus Corridor

Type Onroad	**Engine Model Year** 2008	**Fuel Type** Biodiesel 5
Target Transit Bus	**Upgrade Year** 2019	**Annual Fuel Gallons** 6,131
Class or Equipment Transit Buses	**Remaining Life** 5	**Annual Miles Traveled** 44,782
Quantity 300		**Annual Idling Hours** 340

Edit Group | Copy This Group | Delete

Upgrades to New Bus Corridor

Action	Upgrade	Cost per Unit		Percent Reduction				
		Upgrade	Labor	NO_x	PM2.5	HC	CO	CO_2
Edit Delete	Diesel Oxidation Catalyst	$1,000	$1,000	0	20	50	40	0
Edit Delete	Diesel Particulate Filter	$1,000	$1,000	0	90	85	75	0
Edit Delete	Biodiesel (B20)	$0	$0	0	0	0	0	0

Figure 10. Project New Bus Corridor. Source: EPA, 2018

The tool offers two different types of results, emission results and health benefits. The emissions results present annual results and lifetime results for baseline and the amount reduced after the modifications proposed in short tons (1 short ton is equal to 2,000 lbs), together with the percent reduced. These data are presented for NOx, PM2.5, HC, CO, CO2 and Fuel. For this last variable the data are presented in gallons. The lifetime short cost effectiveness is also presented, but in USD per short ton reduced. This data is presented in capital cost effectiveness (material and labor costs only) and in total cost effectiveness, that includes all project costs. It is important to note that the tool only includes the costs which one have entered. Figure 11 presents the emission results of the New Bus Corridor project.

Emission Results

Here are the combined results for all groups and upgrades entered for your project.[1]

Annual Results (short tons)[2]	NO_x	PM2.5	HC	CO	CO_2	Fuel[3]
Baseline for Upgraded Vehicles	72.894	0.480	2.551	10.158	20,615.1	1,832,452
Amount Reduced After Upgrades	0.000	0.442	2.359	8.634	0.0	0
Percent Reduced After Upgrades	0.0%	92.0%	92.5%	85.0%	0.0%	0.0%
Lifetime Results (short tons)[2]						
Baseline for Upgraded Vehicles	364.469	2.401	12.753	50.789	103,075.4	9,162,261
Amount Reduced After Upgrades	0.000	2.209	11.797	43.171	0.0	0
Percent Reduced After Upgrades	0.0%	92.0%	92.5%	85.0%	0.0%	0.0%
Lifetime Cost Effectiveness ($/short ton reduced)						
Capital Cost Effectiveness[4] (unit & labor costs only)	$0	$543,240	$101,722	$27,797	$0	
Total Cost Effectiveness[4] (includes all project costs)	$0	$158,445,124	$29,668,872	$8,107,328	$0	

[1] Emissions from the electrical grid are not included in the results.
[2] 1 short ton = 2000 lbs.
[3] In gallons; fuels other than ULSD have been converted to ULSD-equivalent gallons.
[4] Cost effectiveness estimates include only the costs which you have entered.

Figure 11. Emissions Results for Project New Bus Corridor. Source: EPA, 2018

It is possible to see that the reduction in PM2.5, HC and CO are very good, between 85.0% to 92.5%, much higher than the established in measure 1 proposed by the government of Sao Paulo. The problem here is that, once the NOx and CO2 reduction can only be obtained from changing the fuel consumption and we decided to maintain the biodiesel as the fuel of the fleet, the reductions were zero, not achieving the goal established in measure 1. We suggest for a further study to make new simulations changing the fleet fuel. The lifetime cost effectiveness is also impressive. The total amount obtained is USD 196,221,324.00, or 56,1% of the original cost of the project. Which means, that only with the emissions reduction obtained it is possible to pay for more than a half of the project cost. The health benefits are estimated based on the PM2.5 reduction. You have to choose one American county to extrapolate the benefits obtained on the project. According to EPA (2018), annual benefits represent the dollar value of health benefits resulting from reduced exposure of PM2.5. These benefits include the reduction of premature mortality, chronic bronchitis, asthma attacks, non-fatal heart attacks, and other health problems. The dollar values are based on studies used by EPA when estimating the health benefits of environmental rules. The county chose to make this analysis was New York, NY, once we considered that the cities of Sao Paulo and New York face some same problems and have similar size, although they keep lots of different and specific situations. Figure 12 presents the health benefits for the New Bus Corridor project.

County and State	Annual Diesel PM2.5 Reduction (short tons)	Annual Benefits
New York*, New York	0.442	$4,400,000
Total	0.442	$4,400,000

Figure 12. Health Benefits for Project New Bus Corridor. Source: EPA, 2018

The annual benefits obtained was USD 4,400,000.00, which corresponds to 1.26% of the total cost of the project. One observation that we got from the tool, is that when using New York as the comparable American county for this analysis, the benefits could be underestimated for emissions reduction costs because it has a relatively high density when compared to surrounding areas. As a result, this county is likely to be a net exporter of diesel emissions, and some of the benefits on reducing these emissions are likely to take place in downwind counties. Once the same situation could occur in Sao Paulo, that should also be a diesel emissions exporter, we considered the analysis valid to consider and we decided to include it on this paper.

Conclusions

In this work, we analyzed the actual situation of the city of Sao Paulo, Brazil, in terms of urbanization and the impact in its environmental conditions. The city has geographically grown indiscriminately in the last years, with low investment in public transportation. The fleet of cars increased a lot, causing congestion on its streets. With more cars on the streets, the air quality of the city remains not good, away from international acceptable standards. Inequality in the city is high. The differences in health care, education, mobility, culture, sports, and housing lead to a significant difference in the life expectancy of the population, reaching the limit of seventy-nine years in prime areas of the city against fifty-five years in the poorest southern regions. These regions are the same that have the worst urban infrastructure and environmental conditions. The goal of this work was to evaluate the urban development of Sao Paulo, that seems to be not structured, the impacts it could generate on the environmental conditions of the city, propose measures and calculate the impact of these measures to improve the sustainability of the city. We evaluated fifteen technical indicators for the city: population growth, urbanized area, fleet of cars, congestion index, use of active transport modes, use of public transportation, traffic deaths, housing units for social use, reduction of floodable areas, plant cover index, number of fall trees, air quality PM 2.5, general air quality, rain and waste sent to landfills. Then, based on the results obtained, we proposed 4 improvement measures: reduce in 15% the emissions of CO2, in 50% the emissions of PM2.5 and in 40% the emissions of NOx by the bus fleet of the city until 2020; carry out safety assessment and promote adequacy of geometry and signaling in eight corridors of public transport to improve safety conditions; build and put in operation 72 kilometers of bus corridors; and increase by 7% the use of public transport.

To estimate the effect of the renew of bus corridors in the city and the impact of this action on the emissions, we ran a pilot project in the DEQ tool. The results obtained by the pilot are promising. For a renew bus corridor project of total cost of USD 350 million, the return just in terms of reduced emissions was estimated to be USD 196 million, or 56% of the investment. To improve the city environmental conditions, Sao Paulo first needs to invest in its urban development, like the solution of the traffic jams. This will decrease the pollution in the city and improve the health conditions of the population. The third step should be in the increase of employment, which will reduce the social inequality. And, the fourth point to be solved is the improvement of the public services. Despite being the richest city in the country, the food and health situation of São Paulo is also not adequate. Sao Paulo is not usually on the list of the best cities to live in Brazil, mainly due to the values of the indicators presented above. The paulistano (how is called the inhabitant of the city) cannot be considered an extremely happy people. Problems such as heavy traffic, violence, unemployment and pollution make many citizens with the wish to leave the city. But on the other hand, the job and study opportunities offered by the city hold people here. The ample supply options of leisure and fun compensate a little this equation. Trying to improve the life conditions in the city is the job of the government. Searching for solutions for the cities' problems should be their first task every day they go to their offices. Tools like the DEQ, can help make the cities more sustainable or, in other words, a city where its resources are available for the population use to improve its quality of life, without causing damage to the environment. The improvement in the population´s quality of life will generate impacts on income, employment, services and happiness. The disordered growth of Sao Paulo is related to the worsening of sustainability situation of the city. Both affect the quality of life of the city´s population, but with this research, it is difficult to establish a cause and effect relation. This is a suggestion for further studies related to this subject and the data collected and presented here.

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