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Application of Environmental Cost Accounting to Reduce Emissions and Health Impact in the Greater ABC Region, Brazil

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Abstract: This work shows a proposal for reducing emissions, fuel costs, and respiratory disease hospitalizations using environmental cost accounting principles for the production of biodiesel production from waste frying oil (WFO). PM_{10}, $PM_{2.5}$, and O_3 data from 2017 to 2022 were collected and correlated with the number of hospitalizations for respiratory diseases and their costs. WFO samples were collected locally from households and restaurants in the greater ABC region, Brazil, and biodiesel was produced using the samples. The results showed that throughout the studied period, one or more of the polluting gases showed a strong correlation with hospitalizations due to respiratory diseases, corroborating what has already been verified by other studies carried out by the WHO. WFO biodiesel was within the standard limits, and the total annual production was estimated to be 30,435 m^3; moreover, the associated annual carbon credits would equal 67 tCO_2, as well as a decrease of 30% in total pollutant emissions. Environmental cost accounting revealed that the annual number of respiratory disease hospitalizations could decrease by 3093 and the associated healthcare cost would decrease by USD 838 thousand per year; moreover, the sale of biodiesel and byproducts can generate an annual profit of USD 19 million. The biodiesel plant project had an NPV of USD 172.5 million, a payback of 1 month, and a return on investment of more than 170 times the initial financing. In addition, the reputation and the quality of life of the greater ABC region's residents could improve.

Keywords: environmental cost accounting; human healthcare; greenhouse gas emission; biodiesel; waste frying oil; air pollution

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1. Introduction

1.1. Environmental Cost Accounting Theory

The need for information on how environmental activities can affect the financial performance of an organization has contributed to the further development of accounting tools for use in corporate sustainability practices [1]. In this sense, at a 1988 session of the United Nations Commission on Sustainable Development (CSD 6), there was an attempt to promote the environmental cost accounting theory to world rulers in the context of negotiations on environmentally sound technologies [2].

According to Jasch [3], environmental cost accounting (ECA) is an accounting form that addresses monetary, social, and environmental information, as well as emission mass and flow of energy, in environmental projects. ECA uses activity-based costing (ABC accounting) to evaluate economic, social, and environmental gains based on internal reports focused on cleaner production, improving eco-efficiency, and calculating savings. ECA must contain the internal and external costs, mainly the environmental and social impacts, of all company activities [1]. These environmental and management performances serve as a basis for the decision making of government and private companies [1,4].

The main disadvantage of using ECA is the lack of systematization and of a standard definition of environmental costs, because interests can direct disposal, investment, or external costs, and these influence company revenue and savings [4].

Since this theory was reported, several social, environmental, and economic projects have been developed based on it. Examples are those which have demonstrated the viability of waste reuse in an Austrian brewery [3], a Canadian paper mill [4], and a Brazilian cosmetics company [5], as well as cases of biodiesel from waste frying oil [6], cassava alcohol [7], reuse of civil construction waste [8], and sanitary sewage [1].

1.2. Effects of Air Pollution on Human Health

According to Santana et al. [9], the growth of the world's population, urban development, and energy consumption have as consequences a scarcity of energy sources and an increase in the emission of atmospheric pollutants, which lead to the death of about 6.5 million people per year, with the transport sector being one of the main polluters. According to estimates by the World Health Organization (WHO), more than 227,000 people die from diseases linked to air pollution in America, as well as in countries with low income levels, mainly the most vulnerable groups. People's health, such as in the elderly, children, those with pre-existing chronic diseases, and pregnant and puerperal women, is affected by several respiratory and allergic diseases [10–15]. The main air pollutants are as follows.

Particulate matter smaller than or equal to 10 μm, or PM_{10}, originating due to anthropogenic action creating dust from industrial, road, agricultural, and civil construction activities, as well as that due to natural sources of sea salt, pollen, spores, fungi, and volcanic ash.

Particulate matter smaller than or equal to 2.5 μm, or $PM_{2.5}$, originating from the burning of fossil fuels and biomass and thermal power plants.

Ozone, O_3, concentration, which is not emitted directly into the atmosphere. It is produced through complex chemical reactions between volatile organic compounds (VOCs) and nitrogen oxides (NOx) in the presence of sunlight.

Thus, several studies have been developed to verify the influence of these air pollutants on human health. In the city of São Paulo, Pearson's correlation was applied to data from 2008 to 2018 in order to verify the relationship between hospitalizations for respiratory diseases and pollutant gas emissions, such as CO, PM_{10}, $PM_{2.5}$, NO_2, SO_2, and O_3 [16–19]. In all years, positive correlations were found between most emissions (except O_3) and hospitalizations for respiratory diseases, but the parameters that had a strong correlation were PM_{10} and $PM_{2.5}$ [20,21].

By using an artificial neural network (ANN), Miranda et al. [22] simulated CO, PM_{10}, $PM_{2.5}$, NO_2, O_3, and SO_2 emitted from 2010 to 2017 and their influence on hospitalizations for respiratory diseases in the city of São Paulo. The results showed that the best ANN was able to predict monthly hospitalization and its costs and to contribute to decision making on how much the government should spend on healthcare.

Based on these corrections for gaseous emissions and using biodiesel made from waste frying oil (WFO) in the bus fleet in the city of São Paulo, Santana et al. [9] proved that it is possible to reduce hospitalization costs due to respiratory diseases by 30%, based on the WHO Air Quality Guideline [10,11], and obtain a profit of up to USD 300,000 per year. This demonstrates that it is possible to reduce environmental and social impacts and make a profit by minimizing the effects of polluting gases and replacing diesel oil with biodiesel.

This correlation has also been verified in several countries in Europe, Asia, and America, corroborating studies reported by the WHO [12–15,17,19,21]. Several countries around the world are striving to find solutions to switch from current fuel sources, such as biofuels and green hydrogen [6,21–24]. Green hydrogen is the cleanest fuel ever [25], and the replacement of diesel oil with biodiesel reduced SO_2 by 100%, NOx by 97.95%, N_2O by 96.08%, CO_2 by 99.99%, PM by 91.52%, volatile organic compounds (VOCs) by 91.52%, and methane (CH_4) emissions by 82.28% throughout the production chain [6,24]. The potential of biodiesel in emissions reduction in the road transport sector and its benefits to human health have been verified by Liaquat et al. [26] and Vormittag et al. [27].

1.3. Panorama over the Greater ABC Region

The São Paulo metropolitan region has 22 million inhabitants and is the most populous region in Brazil; there are 47 thousand industries and around 100 thousand commercial establishments. In the southeast is the ABC Paulista or Greater ABC region, which is a traditionally industrial region of the state of São Paulo with a name derived from its three cities: Santo André (A), São Bernardo do Campo (B), and São Caetano do Sul (C) [28].

Figure 1 shows a map of the Greater ABC region. The area of vegetation cover in the cities of Ribeirão Pires, Rio Grande da Serra, São Bernardo do Campo, and Santo André is above 40%; however, the vegetation is exclusively in the region close to Serra do Mar (east and south). This region comprises the watershed protection area (green line), where the Billings dam and several springs and rivers are located. The closer to the city of São Paulo (northwest), the greater the population density and the lower the vegetation indices, so that São Caetano has only 0.1%, Diadema only 5.7% and Mauá only 13.2% vegetation cover [29].

The Greater ABC region is made up of seven cities and has a total of 2,825,048 inhabitants, according to an estimate released by the Brazilian Institute of Geography and Statistics (IBGE). This estimate points to the city of São Bernardo do Campo as the most populous in the region, with 849,874 residents, followed by Santo André (723,889), Mauá (481,725), Diadema (429,550), São Caetano do Sul (162,763), Ribeirão Pires (125,238), and Rio Grande da Serra (52,009) [28].

It is known as the most industrialized region in Brazil, because its industrial park essentially corresponds to the mechanical industry, mainly the automotive industry, but is also composed of the petroleum, pharmaceutical, furniture, and plastic industries. Due to the high rate of industrialization in the region, it concentrates a high circulation of trucks (about 1.86 million vehicles), and there are no mechanisms to reduce these indicators [30]. Federal agencies' reports are important references for social, economic, and demographic indicator use by ABC cities for the elaboration of public policies for the seven cities.

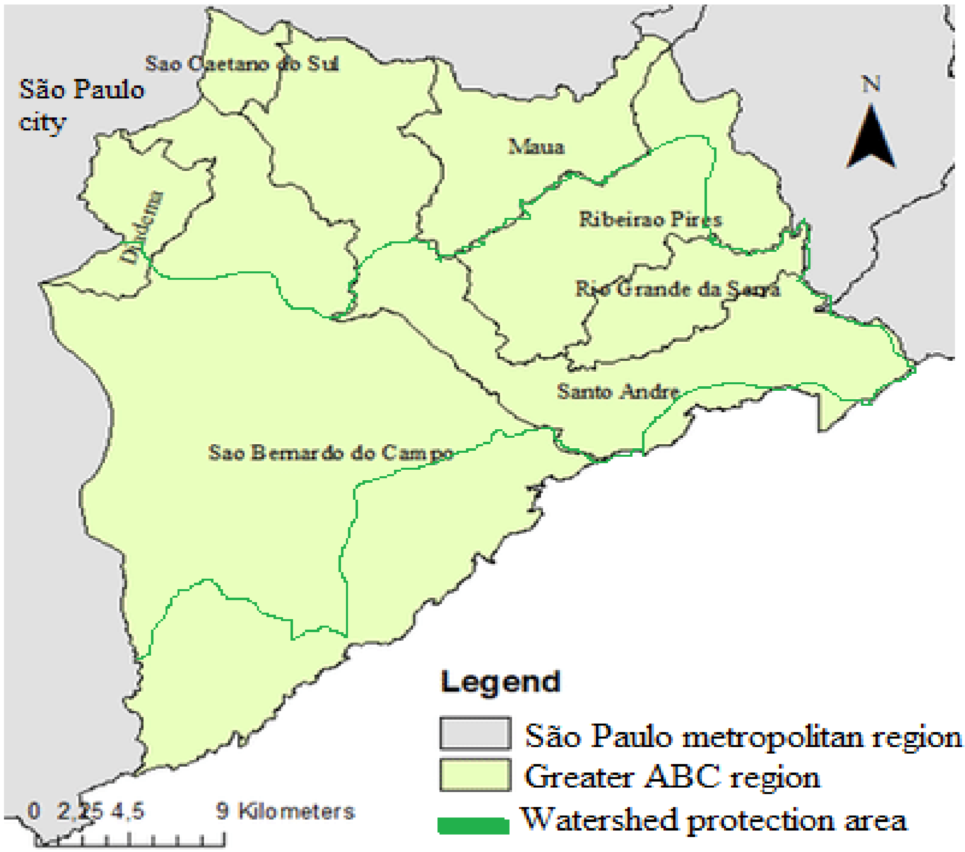

Figure 1. Map of the Greater ABC region. Source: Dunder et al. [29].

A study points out damage to health from inhaling particles resulting from burning fuel. If the levels of urban pollution in the state remain the same, by 2025 it is estimated that 18 people will die per day in the metropolitan region of São Paulo due to complications caused by inhaling substances that are harmful to health [31,32]. São Paulo state has 1.68 inhabitants per vehicle, and concern about the population's health risks from these emissions has been reported for decades [33,34]. Its health system is saturated due to high demand and the hospitalization of sick people caused by these emissions. What I will add is the costs of treating these people and the need to increase the number of beds and hire health technicians to take care of their health.

Therefore, in order to contribute to this topic, this work aimed to show a proposal for emissions, costs, and respiratory disease minimization using environmental cost accounting theory for biodiesel production from waste frying oil (WFO), minimizing the effects of polluting gases by replacing diesel oil. Profits from the sale of biodiesel and from the reduction in expenses from hospitalizations for respiratory diseases were also measured for the Greater ABC region, Brazil.

2. Materials and Methods

2.1. Biodiesel Production

All of the cooking oil used in the experiments was collected from homes and restaurants in the greater ABC region. All procedures are described by Santana et al. [9] and Silva Filho et al. [6], who mixed oil and alcohol (volume ratio of 6:1) in a 3.0 L continuous stirred tank reactor at 60 °C, using 0.1% NaOH (m/v) in a constantly stirred tank reactor for up to 60 min. All biodiesel properties were determined by ASTM methods [6,24,26,35]. The biodiesel yield was calculated using Equation (1):

$$Yield\ (\%) = 94.78 \frac{V_{Biodiesel} \times d_{Biodiesel}}{V_{WFO} \times d_{WFO}} \tag{1}$$

where V and d are the volume and density, respectively, of WFO and biodiesel.

2.2. Data Acquisition on Hospitalization and Gaseous Emissions

In the TABNET-SUS online platform, the monthly data on respiratory disease hospitalizations and their cost were collected. All data were selected from the cities of the ABC region in the period between 2017 and 2019 [9,21,22,32–34]. Research was conducted on the Qualar (air quality) page of the CETESB website, and the monthly pollutant emissions data were filtered for the Greater ABC region [9,21,22], such as in Figure 2. All available data were collected from official sources and represent 100% of the data available on their websites; however, there were interruptions in the supply of data in the period from 2020 to 2021 due to COVID-19.

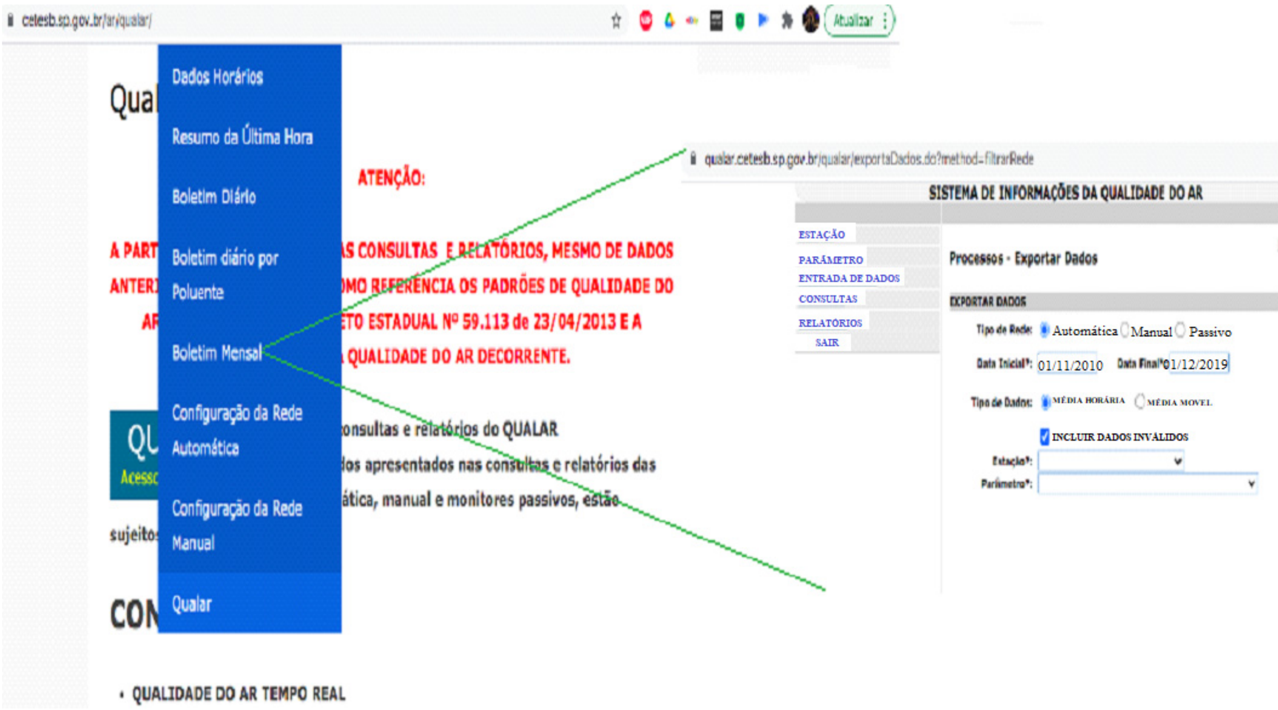

Figure 2. Data collection for gaseous emissions from the official website.

Several sensors were placed in various cities of the ABC region (CETESB [36]). Data on $PM_{2.5}$, PM_{10}, and O_3 were collected in neighborhoods of the cities Santo André, São Bernardo do Campo, São Caetano do Sul, and Diadema e Mauá from 2017 until 2019 in accordance with National Council of the Environment (CONAMA) standards.

Hospitalization data were collected on the TabNet-Datasus website of the Brazilian unified health system (SUS) [29]. Data were collected by selecting the region for the hospitalization data and the specific date. By selecting the International Classification of Diseases (ICD-10) code for respiratory diseases (CID-10 in Portuguese), the quantity and monthly costs were obtained (Figure 3).

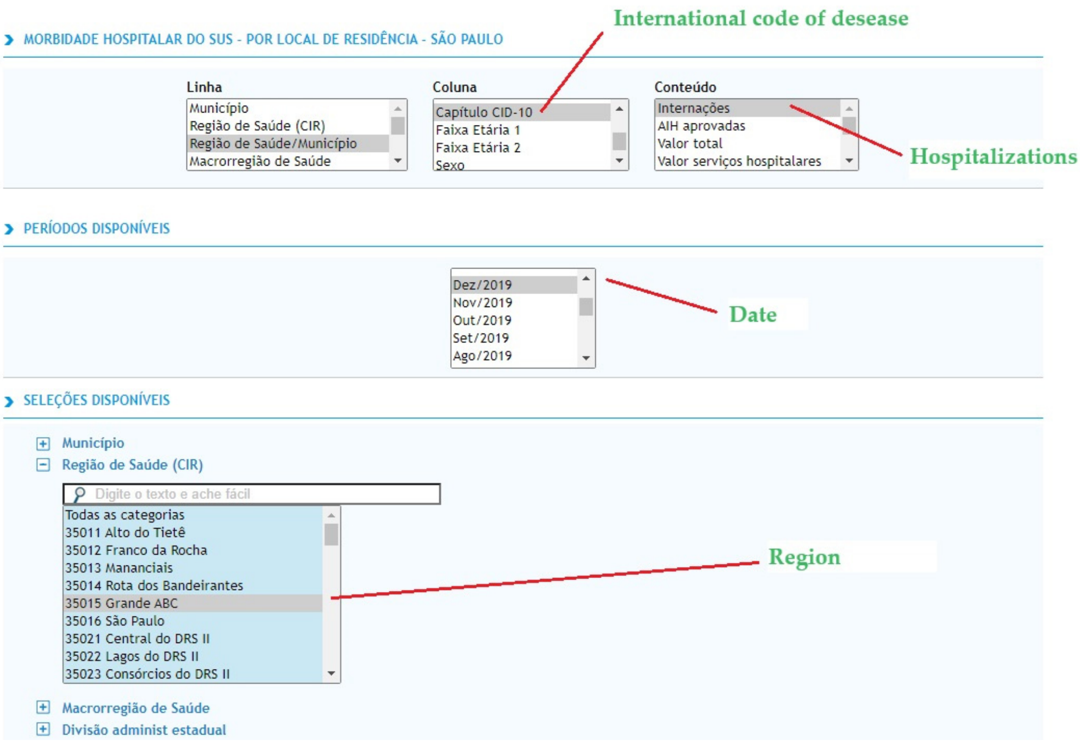

Figure 3. Data collection on respiratory diseases from the SUS official website.

Pearson correlation, r, was used to confirm the hypothesis that "$PM_{2.5}$, PM_{10}, and O_3 emitted by several air sources in the Greater ABC region contribute to increased respiratory disease hospitalizations and their cost" [9,17,18,20–22].

$$r = \frac{\sum(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum(x_i - \overline{x})^2\left(\sum(y_i - \overline{y})^2\right)}} \tag{2}$$

The values for monthly hospitalizations in each city were correlated with the monthly values for each of the polluting gases. This was done for each city, year by year. The sum of hospitalizations for respiratory diseases across all of the cities studied was also correlated with the average values for each pollutant gas's emissions (defined as Greater ABC). Low correlations were considered to be values in the range 0–0.4, average in the range 0.41–0.69, and strong above 0.69 [17,18,20,22].

2.3. Environmental Cost Accounting Strategies

The cost accounting procedure was according to the assumptions of Miranda et al. [35], Santana et al. [9], and Silva Filho et al. [6] as follows:

(a) Overall, 13,200 restaurants and 706,000 households were considered as the population numbers [37];

(b) The WFO monthly average reported by Silva Filho et al. [6] was considered for biodiesel calculation, using Equation (3):

$$V_{WFO}(\mathrm{L}) = \frac{N_1}{n_1} \times \sum_{j=1}^{n_1} x_j + \frac{N_2}{n_2} \times \sum_{k=1}^{n_2} x_k \tag{3}$$

where N and n are the population and the sample, respectively, and j and k denote households and restaurants, respectively;

(c) A reservoir coupled to garbage trucks was used for WFO collection;

(d) A zero net value was therefore considered for WFO collection;

(e) WFO was donated to the city hall so its cost would also be zero;

(f) The monthly WFO volume of the collections and reaction yield were used to calculate the amount of biodiesel with Equation (4), as follows:

$$V_{Biodiesel}(\mathrm{L}) = V_{WFO}(\mathrm{L}) \times Yield \quad (4)$$

(g) Biodiesel revenue was calculated by the use of the sale price and its volume, as follows:

$$Revenue_{Biodiesel}(\mathrm{L}) = V_{Biodiesel}(\mathrm{L}) \times Price(\mathrm{US\$/L}) \quad (5)$$

(h) Biodiesel production was associated with carbon credits, and 2.5 carbon credits were attributed per ton of biodiesel. These carbon credits also contribute to biodiesel production profits and improve the image of the Greater ABC region [6,9,35].

The use of biodiesel enables the reduction of CO_2 emissions and consequently translates into 2.5 carbon credits for each ton of CO_2; the biodiesel carbon credits were calculated using Equation (6) [6,9,35]:

$$CC_{Biodiesel}(\mathrm{ton\ CO_2}) = 2.5 \times m_{Biodiesel} \quad (6)$$

where $m_{Biodiesel}$ is the mass of biodiesel obtained using Equation (7) [6,9,35]:

$$m_{Biodiesel}(\mathrm{ton}) = V_{Biodiesel} \times d_{Biodiesel} \quad (7)$$

where $V_{Biodiesel}$ and $d_{Biodiesel}$ are the volume and density of biodiesel, respectively.

The revenue associated with the sale of carbon credits was obtained using Equation (6) [6,9], as follows:

$$CC\ Revenue\ (\mathrm{US\$}) = tonCO_2 \times Current\ Price\ (\mathrm{US\$/tonCO_2}) \quad (8)$$

The current price of biodiesel is 889.51 US$/m^3 [38].

(i) Revenue from the glycerin generated as a byproduct was also accounted for. The mass of glycerine ($m_{Glycerine}$) was calculated from $m_{Biodiesel}$ using its stoichiometric ratio to biodiesel according to Equation (9), and its profit was determined using Equation (10):

$$m_{Glycerine}(\mathrm{kg}) = \frac{92}{881} \times m_{Biodiesel}(\mathrm{kg}), \quad (9)$$

and

$$Revenue_{Glycerine} = m_{Glycerine}(\mathrm{kg}) \times 14.0\ (\mathrm{US\$/kg}); \quad (10)$$

(j) According to the WHO, the replacement of diesel oil with biodiesel results in 30% less polluting emissions and respiratory disease [9,27]. Proportionally, hospitalization and their costs decreased by 30%, and this was considered in the final accounting. Consequently, the decrease in hospitalization costs was calculated as follows:

$$Hospitalisation\ savings\ (\mathrm{US\$}) = 0.30 \times Total\ hospitalisation\ cost\ (\mathrm{US\$}) \quad (11)$$

All fuel prices and hospitalization costs cited in the paper were retrieved from their original sources [31,38–40], base year 2023, and converted to US$ to avoid fluctuations or the effects of inflation during the period (1 US$ = 5 RBL) [39,40].

Subsequently, the environmental cost accounting was summarized, and the data are presented in a table. The data present the positions and evolutions of the Greater ABC region as it adopted the ecologically friendly system proposed in this study. The steps of the eco-friendly process for discarding WFO are presented in a table at the end of this work [1,6–8].

3. Results and Discussion

3.1. Effects of Polluting Gases on Human Health and Healthcare Costs

The greater ABC region only started to measure air quality from 2017, so the data that are presented represent the history of emissions measurement in the region. Figure 4 depicts the annual variations in PM_{10} emissions in the cities of the Greater ABC region during the study period. From this figure, it is notable that PM_{10} emissions were outside the range recommended by the WHO for 18 months in the first three years. As already reported, exposure for more than 8 h per day to PM_{10} can affect all respiratory systems, causing irritation and inflammation in various organs, which can lead to changes in the shape of the bronchi and even cancer [12–19]. Thus, the population of the greater ABC region is exposed to poor air quality for half of the year and consequently to its harmful effects on health. In the last three years, all values were within WHO standards, which may be an effect of the low circulation of cars due to the lockdown caused by COVID-19.

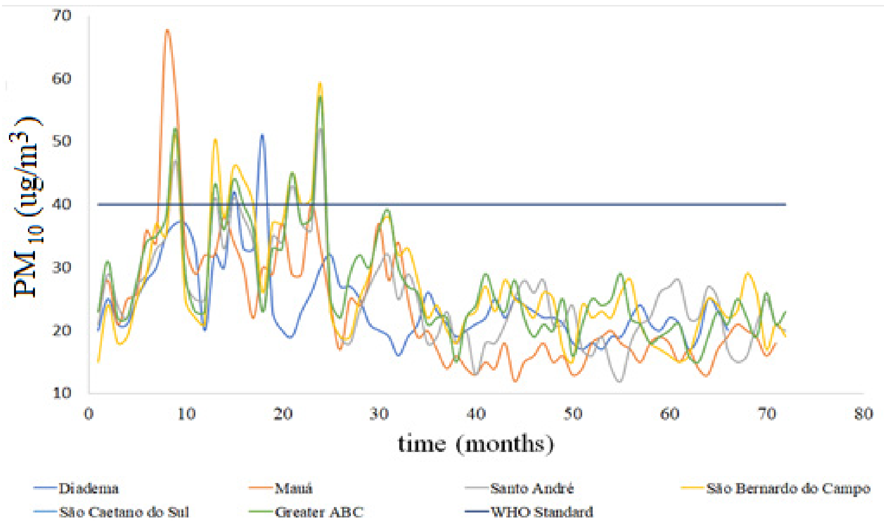

Figure 4. Monthly variation in PM_{10} emissions during the period from 2017 to 2022.

Figure 5 shows the monthly variation in $PM_{2.5}$ emissions in cities of the Greater ABC region during the study period. The city of São Bernando do Campo was the only city that measured $MP_{2.5}$ emissions from the beginning. In the following year, the city of São Caetano do Sul also adopted this parameter as part of its air quality index. The other cities only adopted the $MP_{2.5}$ emission from 2020 onwards.

The emission peaks coincide with the months from August to October, which correspond to the end of winter and the spring season, which is a time of low humidity in the state of São Paulo. During the COVID-19 lockdown period, there was a reduction in the height of the emission peaks, but an increase in the number of months outside WHO air quality standards. From this figure, it is notable that $PM_{2.5}$ emissions were outside the range recommended by the WHO for 10 months from 2017 to 2019 and for 24 months during the last three years. As also reported, exposure for more than 8 h per day to $PM_{2.5}$ can cause all symptoms associated with PM_{10} exposure, added to inflammation of the airways, itching, mucus production, and runny nose and cough, which can lead to death in children, alongside increased blood pressure in sensitive people exposed to outdoor air [12–19]. This drives the population of the greater ABC region's exposure to poor air quality for half the year and consequently its harmful effects on health [12–19].

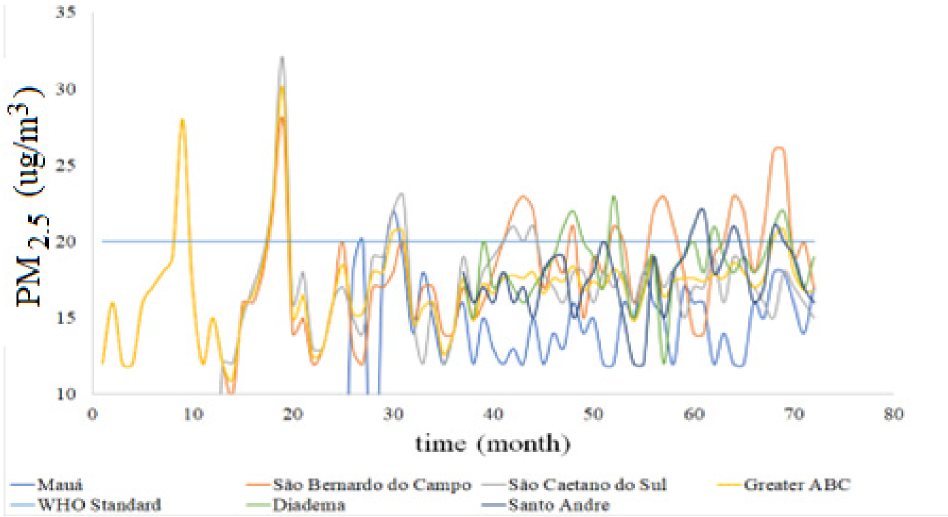

Figure 5. Monthly variation in $PM_{2.5}$ emissions during the period from 2017 to 2022.

Figure 6 shows the variation in ozone concentration during the period studied. Unlike the behavior of the other parameters, ozone has concentration peaks at the beginning and end of the year, corresponding to the summer and autumn seasons. In the last two years, there has been a sharp increase in ozone emissions in the region. Only the city of Mauá showed a drop in emissions. Even so, this parameter was outside the air quality range for 13 of these 24 months. According to [12–20], exposure for more than 8 h per day to O_3 affects the respiratory system's organs, inducing their inflammation, airway obstruction, coughing, and discomfort, and, in addition, also increasing respiratory and heart problems, mainly in the elderly and children.

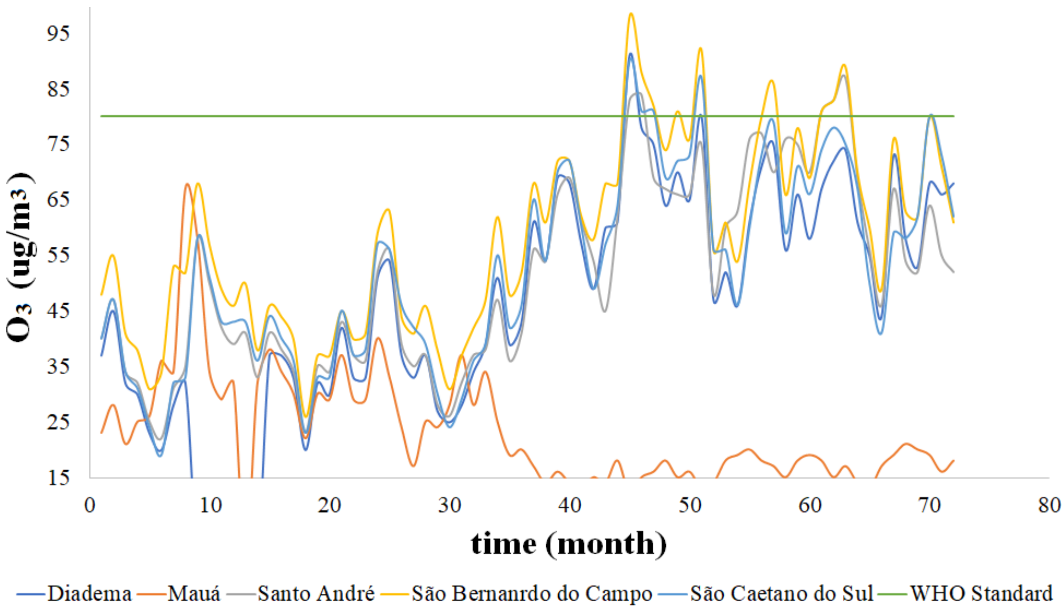

Figure 6. Monthly variation in O_3 concentration during the period from 2017 to 2022.

Figure 7 shows the monthly variation in hospitalization for respiratory disease in the Greater ABC region from 2017 to 2022. From this figure, there are two distinct groups, with one average close to 300 admissions and another below 100 monthly admissions. This is due to the difference between the populations of the cities, as mentioned by [28,29], and also due to the effect of the area of vegetation, which can absorb a good part of the emissions [29].

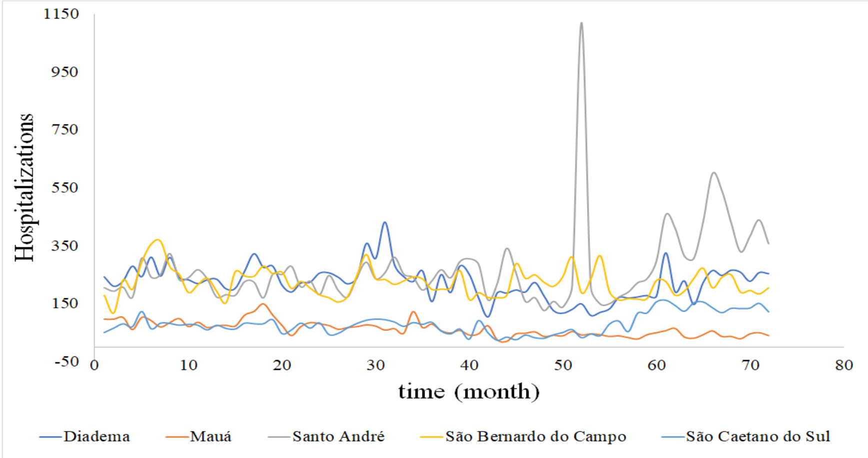

Figure 7. Monthly hospitalization behavior in cities of the Greater ABC region during the period studied.

Note that the hospitalization values show slight oscillations, with a peak around the ninth month of each year. These peaks corroborate data on the increase in emissions in dry seasons, as shown in Figures 4 and 5. The effect of covid is also observed in the elevation of the peaks in the final months of this survey. This occurred due to the confusion of data exclusively on respiratory diseases with data on COVID-19.

The worst air quality values are observed in the months of July to September, and this reflects an increase in hospitalizations in the following month; according to Santana et al. [6], Santana et al. [21], Miranda et al. [22], and Natali et al. [41], in September there is a peak in hospitalizations for respiratory diseases in the city of São Paulo. These months also comprise the period of low rainfall and humidity, which can also influence the increase in respiratory diseases.

PM_{10} emissions are associated with premature deaths due to heart and respiratory diseases [16,23]. Excessive exposure to $PM_{2.5}$ emissions can cause various respiratory diseases in children and pregnant women and increased blood pressure in hypertensive people, as mentioned in current literature [12–19,42,43]. The increase in hospitalization for chronic obstructive pulmonary disease (COPD) is associated with $PM_{2.5}$, PM_{10}, and NO_2 emissions [35,42–44].

Table 1 summarizes annual hospitalizations and their costs for the Greater ABC region from 2017 to 2022. During the study period, the Greater ABC region had more than 60,000 hospitalizations, with a total cost of almost US$ 17 million; 83% of this hospitalization was carried out in the cities of Santo André (31.3%), Diadema (26.2%), and São Bernardo do Campo (25.9%). The relationship between emissions and hospitalizations, which was reported for several cities worldwide, has also been documented for Greater ABC cities.

Table 2 shows the Pearson correlation between polluting gas emissions and hospitalizations for respiratory diseases, correlated year by year for each city, and for the Greater ABC region. As shown in this table, PM_{10} emissions showed the highest correlations with hospitalizations for respiratory diseases for all cities in the greater ABC region. However, this may have been influenced by the lack of measurement of $PM_{2.5}$ emissions in the early years of the survey. The city of São Caetano do Sul had the highest number of positive correlations between gaseous emissions and hospitalizations for respiratory diseases, most of which were medium to high. Ozone has reversed its correlation from negative to positive in recent years, which corresponds to the sudden increase in its concentration, as shown in Figure 5.

Table 1. Annual values of hospitalizations for respiratory disease in Greater ABC cities.

City	Diadema		Mauá		Santo André		São Bernardo		São Caetano	
Year	**Hosp**	**Cost (US$)**	**Hosp**	**Cost (US$)**	**Hosp**	**Cost (US$)**	**Hosp**	**Cost (US$)**	**Hosp**	**Cost (US$)**
2017	3001	540,040.53	1020	270,234.7	2874	639,620.3	2918	924,030.64	912	285,135.7
2018	2891	600,787.65	1059	262,271.6	2552	675,723.8	2707	825,452.36	884	213,340.8
2019	3234	599,250.8	856	227,507.1	2871	691,335.7	2666	775,230.46	935	243,045.1
2020	2413	427,723.81	543	198,671.3	2827	101,2378	2546	992,826.92	526	157,045.9
2021	1761	324,764.92	483	133,184.9	3247	656,011.6	2590	1,000,456.5	889	256,716.1
2022	2896	681,604.35	514	186,569.1	4995	1,368,252	2582	1,127,338.1	1669	461,195.8
Average	2699	529,028.68	746	213,073.1	3228	840,553.5	2668	940,889.17	969	269,413.2
Total	16,196	317,4172.1	4475	127,8439	19,366	5,043,321	16,009	5,645,335	5815	1,616,479
	Greater ABC hospitalization						Greater ABC total cost			
Average	10,310	Total	61,861			Average	2,792,956	Total		16,757,746

Table 2. Pearson correlation between polluting gas emissions and hospitalizations for respiratory diseases.

City	Pearson for Santo André			Pearson for São Bernardo			Pearson for São Caetano		
Year	**MP_{10}**	**$MP_{2.5}$**	**O_3**	**MP_{10}**	**$MP_{2.5}$**	**O_3**	**MP_{10}**	**$MP_{2.5}$**	**O_3**
2017	0.7	-	−0.6	0.7	0.6	−0.4	0.1	-	1.0
2018	0.1	-	0.1	−0.9	0.7	−0.4	0.6	0.5	−0.6
2019	0.6	-	−0.2	0.7	0.4	−0.5	0.5	0.6	0.9
2020	0.3	−0.4	0.4	−0.3	−0.6	0.4	0.6	0.4	−0.3
2021	0.3	−0.4	0.4	−0.4	0.6	−0.2	0.9	0.4	0.4
2022	0.5	0.3	0.3	0.7	0.6	0.1	0.2	0.0	0.7
City	**Pearson for Mauá**			**Pearson for Diadema**			**Pearson for the Greater ABC region**		
2017	0.2	-	−0.2	0.5	-	−0.6	0.7	0.7	−0.8
2018	−0.7	-	−0.7	−0.2	-	−0.2	−0.6	0.8	−0.5
2019	−0.3	-	0.3	0.9	-	−0.5	0.8	0.7	−0.5
2020	0.2	−0.4	0.7	−0.1	0.0	0.1	0.8	0.4	0.9
2021	0.9	0.6	−0.3	−0.6	0.4	0.8	0.1	0.6	−0.5
2022	0.3	−0.2	−0.2	0.2	−0.4	−0.1	0.4	−0.4	0.8

Thus, based on Equation (11), if the policy of replacing diesel oil with biodiesel were adopted, the Greater ABC region could reduce the number of annual respiratory disease hospitalizations by approximately 3.093 patients and US$ 838 thousand per year [10,11]. Consequently, extending the forecast to ten years of the project, using the average savings for hospitalizations and a rate of 5% p.a. (Brazilian inflation forecast), it is possible to obtain a total saving of US$ 6.47 million. This amount is enough for the construction of more than 40 medium-sized hospitals (50 to 100 beds).

Analyzing by city, 52% of medium to strong correlations were due to PM_{10}, 28% due to $PM_{2.5}$, and 20% due to O_3. This may have been influenced by the lack of $PM_{2.5}$ measurements in the first few years for several cities. However, throughout the greater ABC, $PM_{2.5}$ had the greatest influence (40%), followed by PM_{10} (30%) and O_3 (20%). Santana et al. [21] observed that $PM_{2.5}$ was responsible for 65.8% of the total number of poor-air-quality-related hospitalizations in São Paulo city, followed by PM_{10} (29.6%) and O_3 (4.6%).

Thus, various symptoms and respiratory diseases can arise because of exposure to these air pollutants, which can cause bronchial asthma and allergic respiratory diseases, increase mortality in children, and increase blood pressure in outdoor workers [9–12].

3.2. Environmental Cost Accounting Analysis

It was proven that the replacement of diesel oil with biodiesel reduced gaseous emissions by more than 90%, with benefits to human health [6,22]. Thus, WFO collected in cities in the Greater ABC region was used for the production of biodiesel, and Table 3 shows the results for its characterization. Table 4 shows biodiesel quality assessment data based on the WFO mixture (residences and restaurants). All of the physicochemical properties of the obtained biodiesel were within national biodiesel standards, with an average biodiesel yield close to 94%, and the purity of the obtained biodiesel samples was 98.35 ± 0.15% (more than 96.5%) [6,9,35,45].

Table 3. Properties of biodiesel obtained from waste cooking oil mixture.

Source	Yield (%)	Density (g/mL)	Acid Value (g/100 g)	Moisture (g/100 g)	Flash Point (°C)	Viscosity (mm^2/s)
Biodiesel	94.13 ± 4.57	0.8803 ± 0.0512	0.3219 ± 0.2134	0.021 ± 0.003	50.0 ± 0.3	4.0 ± 0.5
ANP	-	0.875–0.900	<0.8	<0.5	>38	3.0–6.0

Table 4. Current annual balance of capital outflows.

Description	Quantity (unit/year)	Unit Cost (US$)	Total Cost (US$/year)
Investment	1	1,000,000.00	109,875.30
Plant depreciation	1/12 *	800,000.00	66,666.67
Maintenance (%)	0.04	6666.67	2666.67
Anhydride Ethanol (m^3)	5072.64	587.52	2,980,277.02
Wages and fees	267.13 *	1000.00	2,667,133.20
Tributes	0.18 on revenue		4,936,080.42
	Annual total cost (US$)		8,362,699.32

* The useful life of the plant = 10 years or 120 months; the salary is 13.33 plus a fee of 67%.

The proposal involves a WFO biodiesel production plant and a proposed cash flow that includes the acquisition of anhydride ethanol, and production of biodiesel for such a plant is presented in Table 4 [6]. It was assumed that the WFO was donated by Greater ABC residents, and, therefore, no cost was associated with it; moreover, the transportation cost was not included because the WFO was collected at the same time that garbage was collected [6,35].

For this volume of biodiesel, a biodiesel production plant with an output of 4 m^3/h would be sufficient. The market start-up price for a similar plant is US$ 800 thousand [6,9]. Financing of 1 million dollars was requested from a bank for 10 years, with a rate of 1.75% for year calculated with a constant installment system (Price table), which generates an annual installment equal to US$ 109,875.30. The service life of the equipment was 10 years, and a 4% maintenance cost was added to the proposal at an annual cost of US$ 2666.676. The annual wage cost for 12 employees earning $1000/month was determined using 13.33 salaries plus 67% fees on wages (13.33 = 12 salaries + 13th salary + vacation) and was equal to US$ 267 thousand (3.2% total cost). The consumption of anhydrous ethanol was equal to 16.67% of the consumption of frying oil, and its total cost was US$ 2.98 million, which is equal to 35.6% of the total costs. In Brazil, tributes are levied on revenue, and even if its value is 18% of revenue this is equivalent to 59% of the total costs.

According to the city hall consortium of the Greater ABC region [28], its cities and had a total of 2,825,048 inhabitants, living in 706,000 residences and consuming food from 13,200 restaurants [37]. In a survey with more than 2000 respondents, it was determined that the amounts of WFO produced in homes and restaurants in São Paulo were 2.245 and 97.663 L/month, respectively [6]. Using these values in Equation (3), a WFO amount of 2756.923 m^3/month was obtained.

After reaction with anhydrous ethanol, and according to Equation (4), this can produce 2536.320 m^3 of biodiesel per month, considering a 94% yield. This value is four times higher than the monthly amount of diesel oil consumed by the bus fleet in the greater ABC region (559 m^3/month) [28]. From the produced biodiesel, 234.136 kg of glycerin and 5.605 tCO_2 of carbon credits are also obtained per month. To assemble the cash flow, these values were multiplied by 12 to obtain their annual value.

Table 5 presents the annualized amounts of biodiesel and byproducts and their revenues, to compare with the cash flow in Table 4 and obtain the annual profit [46]. Note that the annual revenue exceeds US$ 27.4 million, with profit at US$ 19.0 million. This is much greater than the total investment made, indicating that the project is highly profitable. It is also notable that even the annual savings on hospitalization for respiratory diseases would be enough to buy the biodiesel plant.

Table 5. Current annual balance of capital inflow.

Description	Quantity (unit/year)	Price (US$)	* Unit Revenue (US$/year)
Biodiesel, m^3	30,435.84	899.51	27,377,216.71
Glycerine, kg	2809.63	14.00	39,334.84
Carbon credit, tCO_2	67.2632	90.95	6117.45
Total revenue		27,422,669.00	
Profit from biodiesel, US$/year		19,059,969.69	
Saving from public health, US$/year *		837,887.32	

* Not used in revenue calculation (calculated with Equation (11)).

After an economic analysis of the financing of the biodiesel production project using WFO collected in residences and restaurants of the Greater ABC region, Table 6 and Figure 8 were prepared. To obtain the data in Table 6, financing of US$ 1 million, for 10 years, with a financing rate of 1.75% p.a. and installments calculated using a price table (financing system with constant installments), was considered, as previously mentioned. After cash flow analysis, the biodiesel plant project had a net present value (NPV) of US$ 172.5 million, with an internal return rate (IRR) of 1906% and a payback of 1 month. The return on investment (ROI) was 17,247%, which indicates that the NPV is more than 170 times the initial financing at the end of the project, demonstrating that the project is very profitable [46].

Table 6. Economic analysis of the biodiesel production project from waste frying oil.

Description	Value
Net present value, NPV (US$)	172,469,032.88
Internal return rate, IRR (%)	1906
Rate of return on investment, ROI (%)	17,247
Payback (months)	0.63

Figure 8 presents sensitivity analysis for the project considering the influence of funding time and the minimum attractiveness rate (MAR). Figure 8a shows the variation in NPV with project time, while Figure 8b shows the variation in this same parameter with the MAR rate used in financing. It is noted that the project is very stable, presenting high profitability in all of the analyzed conditions [46]. In addition, the city's reputation and the quality of life of Greater ABC region residents could improve [46].

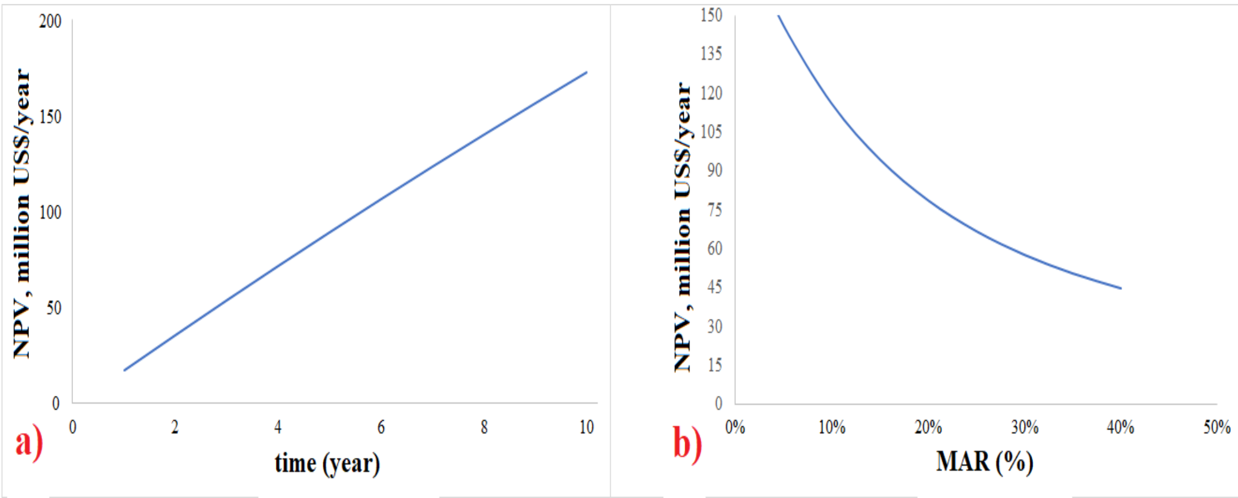

Figure 8. Sensitivity analysis for the biodiesel production project. NPV variation with (**a**) time and (**b**) minimum attractiveness rate.

According to Miranda et al. [35], Santana et al. [9], and Silva Filho et al. [6], for greater efficiency in the biodiesel production project and to use it to replace fossil fuels, it is necessary to make the population of the Greater ABC region aware of the need to store WFO for collection in garbage trucks. These trucks must be fitted with a tank for WFO collection. For this, full participation of the players in the consortium of city halls of the Greater ABC region is necessary. After implementing the policies based on environmental cost accounting, Greater ABC cities could benefit as follows in Table 7. Table 7 shows the sustainable stages of environmental cost accounting for the biodiesel project of biodiesel production for the Greater ABC region.

Table 7. Sustainable stages of environmental cost accounting for the biodiesel project.

Field	Environmental	Social	Economic
Stage 1 Unsustainable	- Excessive use of fossil fuel; - Pollutant gaseous emissions above WHO levels; - Misuse and incorrect disposal of WFO.	- Increased numbers of patients and deaths; - Hospitals with saturated beds from these patients; - Cities with a bad reputation because of higher air, water, and soil pollution and respiratory diseases.	- High costs associated with fuel purchase, removal of oil during water and wastewater treatment, and hospitalization of patients [6].
Stage 2 First actions	- Public awareness via motivational campaigns and incentives for the proper storage and collection of WFO [6].	- Population motivation and awareness of the effects of gaseous emissions from fossil fuels [6].	- Costs of advertising, lectures, and building the biodiesel plant.
Stage 3 Sustainable	- The consortium of the Greater ABC region starts WFO collection; - Start of biodiesel production and fuel replacement; - Zero disposal of WFO.	- Decrease in the number of hospitalizations and deaths; - Decrease in the occupation of hospital beds; - Improving the image of Greater ABC cities.	- Initial savings on WFO collection, sewage treatment, and hospitalization.

Table 7. *Cont.*

Field	Environmental	Social	Economic
Stage 4 Fully Sustainable	- Partial replacement of fossil fuel with biodiesel; - Gain of 67 tCO_2 of carbon credits per year; - Reduction in pollutant emissions by more than 90%; - Elimination of irregular disposal of WFO.	- Improvements in air and water quality in the Greater ABC region; - Reduction of 3093 patients/year and increase in available hospital beds; - Improvements in quality of life and in the Greater ABC's image.	- Annual gain of US$ 19 million from the sale of biodiesel, carbon credits, and glycerine; - A decrease in hospitalization costs by US$ 837,887 per year; - Estimated total profit of US$ 172 million in ten years.

Note that the variability in the amount of frying oil used was not used in the calculations, but this can happen. However, as the amount is relative to a statistical search of more than 3000 stratified samples, a 2% error in this value must be considered. There may also be variation in oil consumption over time due to cultural changes in the population's food consumption. However, remember that the total volume is four times greater than what is needed for the entire city bus fleet. According to Gale [4], the lack of a standard definition of environmental costs affects the results of ECA projects. A variety of costs can be included, such as external costs. For this reason, gains from carbon credits and hospitalization costs were not included in the project's cash flow.

4. Conclusions

From the datasets on gaseous pollution in Greater ABC cities, it was noted that the emission levels of PM_{10}, $PM_{2.5}$, and O_3 were higher than the WHO-established values throughout the study period, indicating that the air quality in São Paulo city was poor throughout the study period.

During the study period, approximately 62,000 respiratory disease hospitalizations were recorded, which translated into a total cost close to US$ 17 million for the Brazilian healthcare system.

These costs are related to PM_{10}, $PM_{2.5}$, and O_3 emissions, because throughout the studied period one or more of these parameters presented a strong correction with hospitalizations due to respiratory diseases.

The biodiesels produced from restaurant and residence WFO were within standard limits, and production of 30,435 m^3/year was estimated; moreover, the associated annual carbon credits would equal 67 tCO_2, with a decrease of 90% in total pollutant emissions and of 30% in the hospitalizations due to it.

Environmental cost accounting revealed that there were annual decreases in hospitalizations representing 3093 patients and US$ 837,883 in costs; moreover, the sale of biodiesel and its byproducts can generate an annual profit of US$ 19 million. The biodiesel plant project had an NPV of US$ 172.5 million, with a payback of 1 month and a return on investment of more than 170 times the initial financing. In addition, the reputation and the quality of life of the Greater ABC region's residents could improve.

This proposal can be adopted by the governors of other cities, which, together with other ecofriendly actions, will help to minimize the effects of atmospheric pollutants on the environment, economy, and human health, thus improving the quality of life of citizens.

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