Aerosol and Air Quality Research, x: 1–8, xxxx
Copyright © Taiwan Association for Aerosol Research
ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2017.11.0449

Assessment and Valuation of Public Health Impacts from Gradual Biodiesel Implementation in the Transport Energy Matrix in Brazil

Evangelina M.P.A. Vormittag[1*], Cristina Guimarães Rodrigues[1], Paulo Afonso de André[2], Paulo Hilário Nascimento Saldiva[3]

[1] *Instituto Saúde e Sustentabilidade, São Paulo, SP, Brazil*
[2] *Laboratório de Poluição Atmosférica Experimental, Faculdade de Medicina da Universidade de São Paulo, São Paulo, SP, Brazil*
[3] *Departamento de Patologia, Faculdade de Medicina and Instituto de Estudos Avançados da Universidade de São Paulo, São Paulo, SP, Brazil*

ABSTRACT

Carbon dioxide from fossil fuels and industrial processes accounted for approximately 78% of the total increase in greenhouse gas emissions from 1970–2010. The economic advantages of reducing fossil fuel combustion and improving air quality, including a reduction in chronic diseases and their associated health care costs, and the economic opportunities associated with the development of alternative energy sources are undoubtedly one of the main initiatives to be defined by governments in the sphere of public health. The objective of this study is to estimate the impact of the addition of different levels of biodiesel to diesel for automotive use on public health, considering changes in the ambient concentration of fine particles. Considering the two most populous metropolitan areas in Brazil, São Paulo and Rio de Janeiro, for a period of 11 years (2015–2025), by increasing the percentage of biodiesel to 20% (B20), it is estimated that there would be 13,000 fewer deaths and a gain generated from the avoided lost productivity of more than US$ 816 million. A total of 28,000 hospitalizations through the public health system would be avoided, generating a cost savings of US$ 25 million. Against the backdrop of a lack of policies and initiatives to combat air pollution, the magnitude of the results points to the importance of such a study in guiding the decisions of government officials with regard to how a city intervention—the addition of biodiesel to improve air quality—will bring a consequent benefit in the area of health.

Keywords: Biofuel policies; Particulate matter; Air pollution; Health impact assessment; Public policies.

INTRODUCTION

Reductions in GHG emissions are critical to minimizing climate change. Biodiesel has been considered to be among the alternatives for fueling heavy duty vehicles because of its advantageous CO_2 balance. In the official 68th World Health Assembly report in May 2015, the World Health Organization (WHO) concluded that the reduction of air pollution-related health impacts can be a health-relevant indicator for sustainable development policies. The WHO officially invited member states to support the initiatives to monitor and combat pollutant emissions. In this context, when adopting new fuel alternatives, the corresponding effects should be addressed in terms of the emissions of local pollutants. Recently, the WHO estimated that approximately 8 million premature deaths worldwide are caused by local pollutants: 3.7 million deaths are attributed to external air pollution, and 4.3 million deaths are attributed to indoor air pollution (WHO, 2015a), using ambient concentrations of fine particles ($PM_{2.5}$) as a reference. $PM_{2.5}$ is the pollutant that is most consistently associated with adverse health outcomes, such as respiratory and cardiovascular diseases (Pope *et al.*, 2002) and lung cancer (Hamra *et al.*, 2014). Diesel emissions are the main automotive source of $PM_{2.5}$ in São Paulo. According to the Air Quality Report (CETESB, 2014), the contribution to $PM_{2.5}$ by diesel is 49.5%. Biodiesel has been considered to be among the alternatives to diesel to run heavy duty vehicles because of its low GHG emissions. However, its effect on public health (due to local pollutants such as fine particles) has not been fully established. As a general rule, a heavy duty engine emits fewer particles when biodiesel is utilized (Pinto *et al.*, 2005). The objective of this study is to estimate the impact of the addition of different levels of biodiesel to diesel on public health, considering changes in the ambient concentrations of fine particles.

---

[*] Corresponding author.
Tel.: 55 11 3759 0472
E-mail address: vanjav@saudeesustentabilidade.org.br

METHODOLOGY

The environmental indicator that was adopted in the intervention scenario is fine inhalable particulate matter ($PM_{2.5}$), which is recommended by the WHO (WHO, 2006) for health assessment studies on environmental impact.

Some simulations were conducted in the metropolitan area of São Paulo (MASP) and the metropolitan area of Rio de Janeiro (MARJ), which were chosen for their extensive diesel fleet and significant diesel source contribution to atmospheric pollution. In 2012[1], the mean annual daily $PM_{2.5}$ levels were 21.6 µg m^{-3} in the MASP and 24.8 µg m^{-3} in the MARJ.

The simulated biodiesel contribution in the study scenario was set to 7% (B7) and 20% (B20)[2]—scenarios of different blends of biodiesel (percentage increase of biofuel per liter of mineral diesel)—compared with 5% (B5) biodiesel addition to diesel, considering the base year 2012. The period for the simulation was ten years—from 2015 to 2025—considering the same level of PM concentration as 2012 for all years.

Based on the determination of the PM emission share of the diesel source, the next step was to determine the decrease in PM emissions with different biodiesel blends (Giakoumis *et al.*, 2012). The B7 case shows a 1.6% reduction in $PM_{2.5}$ emissions compared with B5 and a 9.6% reduction compared with B20. The health impact is assessed based on the reference value (standard) of $PM_{2.5}$ levels of 10 µg m^{-3} (annual mean) established by the World Health Organization, which is the lowest pollutant level with a significant effect on health.

This study estimates the impact of biodiesel health effects (contribution of the gradual addition of biodiesel to the energy matrix) by the number of hospitalizations due to diseases that are related to air pollution (respiratory and cardiocerebrovascular diseases and lung cancer) and mortality rates based on the environmental results. The burden of diseases that are attributable to air pollution is calculated according to the method proposed by the WHO (Ostro, 2004; WHO, 2006). The methodological steps are employed to estimate the relative risk of exposure to air pollution, which is used to calculate the air pollution-attributable fraction of health outcomes, and the number of air pollution-attributable health events (Rodrigues *et al.*, 2015; WHO, 2006) for each scenario: reference scenario—with 5% biodiesel—and alternative scenarios—with 7% and 20% biodiesel.

The expected benefit from the gradual addition of biodiesel is given by

$$Y^{BX} = \mathrm{PM}_{2.5}^{a} - \mathrm{PM}_{2.5}^{BX} \times Y = \mathrm{PM}_{2.5}^{a} - \mathrm{PM}_{2.5}^{BX} \quad (1)$$

where

Y^{BX} = expected benefit from the addition of different fractions of biodiesel, and BX represents each scenario (B7 and B20) of biodiesel addition.

$\mathrm{PM}_{2.5}^{a}$ = air pollution level of each metropolitan area, considering the standard biodiesel B5 (5% biodiesel per liter of mineral diesel, standard measure), and $\mathrm{PM}_{2.5}^{BX}$ = expected air pollution level when adding each biodiesel fraction (B7 and B20).

The following databases were used to calculate the number of air pollution-attributable deaths and hospitalizations between 2015 and 2025: 1) deaths per five-year age groups in 2012, Mortality Information System (Sistema de Informações de Mortalidade [SIM]) of the Brazilian Ministry of Health (MoH); 2) mortality projections of the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística [IBGE]) until 2025 (2013 Revision); 3) Hospital Information System (Sistema de Informações Hospitalares [SIH]) of the Brazilian MoH, which records all hospitalizations that occur in the public health system (hospitalizations per age group for causes outlined in Table 1 in 2012); and 4) IBGE projections of population growth until 2025 (2013 Revision) to calculate the number of hospitalizations for each cause. Because the IBGE projections pertain to Brazil and the Federative Units (States), the following assumptions were adopted to obtain mortality and hospitalization projections for the study areas: a) the percentage of deaths in each metropolitan area (relative to the total of the Federative Unit) observed in 2012 remains constant throughout the projection period, and b) the hospitalization rate observed in 2012 remains constant throughout the projection period, which is a method known as fixed-rate projection (Finlayson, 2004; Rodrigues *et al.*, 2013).

The beta parameter is needed to calculate the number of air pollution attributable deaths and hospitalizations, as shown in Table 2. This parameter was calculated based on statistics that relate the effect of increased air pollution on health outcomes in different types of studies (time series and cohort, for example)[3].

Economic methodology refers to the valuation of the costs avoided in hospitalizations in the public network and the valuation of deaths that are averted based on the labor productivity method and the gross domestic product (GDP).

---

[1] The year of 2012 was chosen as the last year with available official data on hospital mortality and morbidity from the Ministry of Health. The B5 diesel was the fuel used throughout the year of 2012 by the Brazilian fleet.

[2] When the National Program for the Production and Use of Biodiesel was launched,in 2014, it has defined the mixture of 7% of biodisel in the diesel (B7) sold to the final consumerand, estimated that, by 2020, the program would reach the stage B20, when the concentration of biodiesel added is 20%.

[3] The set of studies used to define beta parameters is the same that used in another study made in Brazil based on real monitoring measures in six largest Brazilian Metropolitan Regions, allowing a comparison between the situation of different times but in the same epidemiological bases.

Table 1. Causes of deaths and hospitalizations included in the projections.

Mortality	ICD-10 group	Age group
1) All deaths	All (ICD-10 chapters I to XVI)	All
Hospitalizations and hospitalization costs	**ICD-10 groups**	**Age groups**
1) Cancer	Malignant neoplasm of trachea, bronchus and lung (ICD C33-C34)	40 years and older
2) Cardiovascular		
Stroke	Stroke, not specified as hemorrhage or infarction (ICD I64)	40 years and older
IH	Intracranial hemorrhage (ICD I60-I62)	
AMI	Acute myocardial infarction (ICD I21-I22)	
CI	Cerebral infarction (ICD I63)	
OIHD	Other ischemic heart diseases (ICD I20, I23-I25)	
3) Resp_children		
Pneumonia	Pneumonia (ICD J12-J18)	Until 5 years of age
4) Resp_adultsz	Bronchitis, emphysema and other chronic obstructive pulmonary diseases (ICD J40-J44)	60 years and older
	Asthma (ICD J45-J46)	
	Pneumonia (ICD J12-J18)	60 years and older

Source: Mortality Information System (SIM) and Hospital Information System (SIH) of the Unified Health System (Sistema Único de Saúde - SUS).

Table 2. Beta parameter used to calculate the relative risk of mortality and morbidity.

Health outcome	Cause	Beta	Source
Mortality	All causes	0.06	WHO (2006)
Hospitalizations	Cardiovascular	0.18	Pope *et al.* (2004)
	Lung cancer	0.40	Hamra *et al.* (2014)
	Respiratory diseases in the elderly	0.31	Cançado *et al.* (2006)
	Pneumonia in children	0.21	Cançado *et al.* (2006)

To calculate the total value of hospitalizations, the mean value of hospitalizations in each age group x to $x + n$ and cause z at time t (${}_n GMe_x^{z,t}$ was multiplied by the number of air pollution-attributable (in the case of B5) and preventable (for additions of B7 and B20) hospitalizations in each year t in the age group x to $x + n$ and cause z (${}_n I_x^{q,z,t}$), which is produced by the hospitalization estimates that are calculated in Eq. (3):

$$G^{z,t} = \sum_x GMe_x^{z,t} \times {}_n I_x^{q,z,t} \tag{3}$$

The average cost of hospitalizations for each cause was kept fixed at the 2012 level. Thus, spending is projected at 2012 prices.

The valuation of deaths from air pollution was performed using the method based on the economic cost of deaths from the total lost productivity given by the GDP. Thus, the number of preventable deaths ($d^{Y,BX}$) for each added biodiesel fraction was multiplied by the GDP per capita in each metropolitan area ($GDP^{2012,MA}$) at 2012 prices in order to have the forecast of cost of death $Z^{t(p)}$:

$$\sum Z^{t(p)} = GDP^{2012,MA} \times d^{Y,BX} \tag{4}$$

Because the GDP *per capita* is not presented by age group, the GDP is multiplied by the total number of deaths regardless of age. The GDP per capita of each metropolitan area was obtained from the time series that was published by the IBGE and calculated at the 2012 value using the IBGE implicit deflator series.

RESULTS

This section reports the results of the projections of deaths, public hospital admissions, cost of public hospital admissions and the valuation of deaths from 2015 to 2025.

Table 3 outlines the number of deaths for five-year periods from 2015 to 2025 for MASP and MARJ, the total number and cost of deaths that are attributable to air pollution in the current scenario of 5% biodiesel from 2015 to 2025, and the numbers avoided due to a gradual increase of 7% and 20% biodiesel in diesel by 2025.

The results indicate that the total number of deaths that are attributable to $PM_{2.5}$ would exceed 56,000 deaths for all causes in the MASP and approximately 51,000 in the MARJ if the current scenario of 5% biodiesel remained constant across all years of the projection. Approximately 1,200 and 7,319 deaths could be avoided in the scenarios of 7% biodiesel adoption and 20% biodiesel adoption in the 10-year period in the MASP, respectively. Approximately 943 deaths and 5,712 deaths would be avoided in the MARJ with the extreme scenarios of 7% biodiesel and 20% biodiesel, respectively.

Table 3. Number of attributable (B5) and preventable deaths for each biodiesel fraction added from 2015 to 2025 – MASP and MARJ[1].

São Paulo	Number of deaths				Cost of deaths (US$ from 2014)			
	2015	2020	2025	2015–2025	2015	2020	2025	2015–2025
Attributable deaths (B5)	4,699	5,118	5,648	56,550	393,553,368	393,553,368	393,553,368	4,735,893,766
Benefit - B7	–100	–109	–120	–1,200	–8,351,909	–8,351,909	–8,351,909	–100,504,196
Benefit - B20	–615	–670	–724	–7,319	–51,264,533	–51,264,533	–51,264,533	–612,732,491
Rio de Janeiro	Number of deaths				Cost of deaths (US$ from 2014)			
	2015	2020	2025	2015–2025	2015	2020	2025	2015–2025
Attributable deaths (B5)	4,39	4,665	5,007	51,474	239,601,945	254,603,758	273,271,594	2,809,207,680
Benefit - B7	–80	–85	–92	–943	–4,389,969	–4,664,863	–5,006,901	–51,470,393
Benefit - B20	–487	–518	–556	–5,712	–26,589,541	–28,254,347	–30,325,990	–311,748,534

Source: Mortality Information System (SIM/DATASUS), IBGE mortality projections (2013 Revision) and the Institute of Applied Economic Research Database (Base de Dados do Instituto de Pesquisa Econômica Aplicada – IPEADATA (2012)).

[1] The average exchange rate of R$/US$ 2.35 from 2014, according to IPEADATA data, was employed.

The number of attributable (B5) or preventable (B7 and B20) deaths over the years increased in all scenarios. Because the pollution scenario was kept constant throughout the projection period, the results are attributed to an increase in the number of projected deaths due to a population increase.

The estimated cost of early deaths that are attributable to air pollution from lost productivity in the current scenario of 5% biodiesel blend would be nearly US$ 5 billion in the MASP and nearly US$ 3 billion in the MARJ from 2015 to 2025. The addition of only 7% biodiesel would cause a gain of more than US$ 100 million from preventable deaths during this period in São Paulo. US$ 612 million in national production (measured by GDP) would not be lost with the maximum addition of biodiesel (20%). In the MARJ, the gain in productivity estimated by the reduction of deaths from 2015 to 2025 would be approximately US$ 51 million with the addition of B7 and approximately US$ 312 million with the addition of B20.

Table 4 outlines the number of air pollution-attributable and preventable public hospital admissions after gradual addition of biodiesel for all selected diseases and the most vulnerable age groups: selected cardiovascular diseases and lung cancer for the percentage of the population older than 40 years and respiratory diseases in the elderly and children (younger than 5 years). In 2015, the number of air pollution-attributable public hospital admissions (B5) was 14,201 in the MASP and 4,736 in the MARJ, which would be 180 thousand for the MASP and 60 thousand for the MARJ in the 10-year period from 2015 to 2025.

Nearly 4,000 public hospital admissions would be avoided in the MASP and approximately 1,000 public hospital admissions would be avoided in the MARJ if 7% biodiesel were added to diesel from 2015 to 2025. Approximately 22,000 hospitalizations in São Paulo would be avoided and more than 6,000 hospitalizations in Rio de Janeiro would be avoided if B20 were adopted since 2015.

The savings generated by reducing hospitalizations in the 2015–2025 period would be approximately US$ 4 million in the MASP and US$ 820 thousand in the MARJ with B7 and approximately US$ 23 million and US$ 5 million by adopting B20 in the MASP and MARJ, respectively, compared with US$ 186 million in the MASP and US$ 48 million in the MARJ spent on public hospital admissions with B5 in the 10-year period.

Table 5 shows the combined results of the number of deaths, public hospital admissions, cost of deaths and spending on public hospital admissions from 2015 to 2025 for MASP and MARJ. More than 108,000 deaths will be observed in 11 years at a cost of lost productivity—slightly higher than US$ 7 billion if 5% biodiesel (B5) prevails. More than 2,000 deaths can be avoided in both metropolitan areas if the percentage of biodiesel in diesel increased to 7% at a cost avoidance of over US$ 134 million. A leap to more than 13,000 prevented deaths and a gain generated from averted lost productivity that exceeds US$ 816 million would occur if the percentage of biodiesel increased to 20% (B20).

DISCUSSION

This study presents the simulated results of adding different proportions of biodiesel to diesel in the heavy duty fleet of São Paulo and Rio de Janeiro. The magnitude of the effects indicates the importance of this study in guiding governmental decisions regarding how city interventions may generate tremendous benefits to the health of the population exposed to air pollution.

The estimated health impact from particulate matter ($PM_{2.5}$) emissions from the B5 blend (5% addition of biodiesel to diesel) on both metropolitan areas was calculated in this study. The impact exceeds 108,000 deaths and 240,000 public hospital admissions, tallied from 2015 to 2025, at a public cost of approximately US$ 7 billion and US$ 207 million (in lost productivity), respectively. Introducing B7 could prevent more than 2,000 early deaths, which would increase to 13,000 if the share of biodiesel in diesel were increased to 20% (B20); these reductions correspond to reduced costs of lost productivity exceeding US$ 134 million and US$ 816 million, respectively. Introducing B7 may reduce public hospital admissions by approximately 4,539, which would increase to 28,000 if

Table 4. Number of air pollution-attributable (B5) and preventable hospitalizations for each fraction of biodiesel added yearly, from 2015 to 2025 – MASP and MARJ[1].

São Paulo	Number of hospitalizations				Cost of hospitalizations (US$ from 2014)			
	2015	2020	2025	2015–2025	2015	2020	2025	2015–2025
Attributable hospitalizations (B5)	14,201	16,297	18,709	179,948	14,364,437	16,877,296	19,630,620	186,184,013
Benefit - B7	–283	–324	–372	–3,583	–287,863	–338,052	–392,99	–3,729,116
Benefit - B20	–1,758	–2,016	–2,265	–22,003	–1,787,431	–2,099,192	–2,390,503	–22,887,907
Rio de Janeiro	Number of hospitalizations				Cost of hospitalizations (US$ from 2014)			
	2015	2020	2025	2015–2025	2015	2020	2025	2015–2025
Attributable hospitalizations (B5)	4,736	5,173	6,156	59,689	3,791,426	4,342,184	4,904,163	47,798,384
Benefit - B7	–80	–92	–104	–1,011	–65,083	–74,511	–84,117	–820,183
Benefit - B20	–490	–555	–636	–6,167	–396,607	–454,077	–512,637	–4,998,260

Source: Mortality Information System (SIM/DATASUS), IBGE mortality projections (2013 Revision) and IPEADATA (2012).

[1] The average exchange rate of R$/US$ 2.35 from 2014, according to IPEADATA data, was employed.

Table 5. Summary of cumulative deaths, cost of deaths, public hospital admissions and spending on public hospital admissions, from 2015 to 2025 – MASP and MARJ[1].

Attributable and preventable mortality and morbidity	Deaths	Cost of deaths (US$ de 2014)	Public hospital admissions	Spending on public hospital admissions (US$ from 2014)
Attributable years of life lost (B5)	108,025	6,665,785,112	239,635	206,713,772
Benefit - B7	–2,143	–134,263,264	–4,593	–4,019,118
Benefit - B20	–13,031	–816,740,754	–28,169	–24,636,275

Source: Mortality Information System (SIM/DATASUS), IBGE mortality projections (2013 Revision) and IPEADATA (2012).

[1] The average exchange rate of R$/US$ 2.66 from 2014, according to IPEADATA data, was employed.

B20 were adopted, saving the country approximately US$ 4 million and US$ 25 million, respectively.

During a recent surge of interest in research, interventions that are designed to reduce pollutant concentrations and improve outcomes associated with human health, responsibility, and accountability—cost-benefit analysis of environmental regulations—have been considered invaluable in their evaluation. Studies indicate that decreased air pollution levels from an intervention generate benefits for public health, particularly with respect to reducing mortality, cardiovascular and respiratory morbidity, and public health spending, which is consistent with our study (Henschel *et al.*, 2012). Several interventions were evaluated: interventions attributed to unintentional air pollution events, such as the strike at a steel mill in Utah Valley, USA (Pope, 1989, Pope *et al.*, 1992; Ransom and Pope, 1992), and interventions aimed at reducing air pollutant emissions, for example, the ban on coal sales in Dublin, Ireland, in 1990 (Kelly and Clancy, 1984; Goodman *et al.*, 2012) or on automobile traffic, such as during the congestion charge trials in London and Stockholm (Tonne *et al.*, 2008; Eliasson *et al.*, 2009; Johanson *et al.*, 2009; Tonne *et al.*, 2009) or during the Atlanta and Beijing Olympics in 1996 and 2008, respectively (Wang *et al.*, 2009; Hou *et al.*, 2010). All cases showed a considerable reduction in the level of air pollutants, including PM_{10} emissions, which reduces mortality rates, especially from respiratory causes. These experiments demonstrated the causal link between air pollution and adverse health effects. Other types of studies employ modeling and other methods to evaluate public policy scenarios, such as the model designed in this study.

For example, modeling studies on the benefits from the 1990 Clean Air Act Amendment in the United States indicated that clean air costs are estimated at US$ 65 billion annually and the benefits total US$ 2 trillion (USEPA, 2015). This finding reveals that the average benefit estimate exceeds costs by a factor of more than 30 to 1 (and the highest estimate exceeds costs by 90 times). The economic benefits from improved worker health and productivity and the savings in air pollution-related health costs out weigh air pollution control costs. Regarding the Clean Air Act, a meta-analysis focused on the benefits from legislation for children; until 2010, the results showed additional benefits in terms of morbidity ranging from approximately US$ 1–2 billion (in 1990 values) to US$ 8 billion (due to hospitalizations, emergency room visits, school absences, and low birth weight) and of mortality ranging from US$ 600 million to US$ 100 billion (USEPA, 2015).

In the US, more than 25 million children breathe polluted air on diesel school buses. In an interesting study about diesel, Adar *et al.* (2015) performed a natural experiment that characterizes the exposure and health of 275 school bus riders before, during, and after the adoption of clean technologies and fuels between 2005 and 2009. The study indicated that fine and ultrafine particle concentrations were 10–50% lower on buses that use ultralow-sulfur diesel (ULSD) and diesel oxidation catalysts (DOCs) and were associated with reduced exhaled nitric oxide (FeNO), greater changes in lung function (FEV1, FVC), and lower absenteeism (−8%), with stronger associations among patients with asthma. To a lesser extent, extrapolating to the U.S. population, DOCs and modified fuels/technologies likely reduced absenteeism by more than 14 million per year.

In this study, the demonstrated benefits from the addition of biodiesel to diesel caused PM emissions reductions using the B7 and B20 blends compared with the B5 blend. Barnwal and Sharma (2005) analyzed greenhouse gas emissions from biodiesel combustion processes and concluded that air pollutant emissions are 15% to 70% lower than the air pollutant emissions reductions from fossil diesel combustion processes.

The effect of the addition of biodiesel to diesel on the concentrations of secondary pollutants, such as ozone (O_3), are more difficult to predict. This study did not assess the health impact of the secondary pollutant ozone from substituting biodiesel. Compared with diesel, the use of biodiesel enhances the emissions of ozone precursors (NO_x) in compression ignition engines. Barnwal and Sharma (2005) showed that NO_x emissions increase by 2.6% with B20 and by 13.3% with B100.

Sánchez-Ccoyllo *et al.* (2006) investigated the effect of reactive hydrocarbons (RHCs) and NO_x sensitivity on ozone production on meteorological variability. They described the impact of three meteorological variables (mixing height, wind speed, and air temperature) on the ozone concentration, the reactive hydrocarbon (RHC) limitation, and the nitrogen oxide (NO_x) limitation on ozone formation in the area. They concluded that the reduction of the RHC emissions inventory by 40% creates the best situation for promoting lower ozone concentrations in the MASP. Therefore, reducing RHC emissions are recommended for the MASP. However, RHC reactivity rates vary; thus, the RHCs that should be reduced in order to better control ozone levels in the MASP need to be determined. Any policy changes aimed at ozone control must consider the RHC/NO_x ratio in the MASP. The reason for the decision to not include ozone is attributed to the limitations on its monitoring and the variables involved in its formation in the MASP, as shown in previous studies. In this context, the beneficial results of biodiesel may be valid in areas where the O_3 photochemistry is similar to that of Brazilian cities.

At the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21), the WHO stated that

> "*health protection should be a priority for investment, and that mitigating climate change can bring large and immediate benefits for health, and for the economy. Policies that reduce carbon emissions can also yield large, local, near-term health benefits for populations at all stages of development. The most obvious gains are from reducing the annual mortality attributable to ambient and household air pollution, which is among the largest causes of death globally. Implementing proven interventions to reduce emissions of short-lived climate pollutants, such as achieving higher vehicle emissions and efficiency standards, would be expected to save approximately 2.4 million lives a year and reduce global warming by approximately 0.5°C by 2050. Placing a price on polluting fuels to compensate their negative health impacts would be expected to cut outdoor air pollution deaths by half, reduce carbon dioxide emissions by more than 20%, and raise approximately US$ 3 trillion per year in revenue – over half the total value of health spending by all of the world's governments*" (WHO, 2015b).

Local health co-benefits from the implementation of sustainable greenhouse gas emission (GEE) reduction strategies, especially in the transport and energy areas, including energy production from renewable or low-carbon sources in addition to fossil fuels, have also been reported in several studies since 2009 (Haines *et al.*, 2009; Nichols *et al.*, 2009; Woodcock *et al.*, 2009; InterAcademy Medical Panel, 2010).

Patz *et al.* (2014) described climate change, and the challenges and opportunities for global health. The consensus is substantial—that human behavior contributes to climate change. Substantial health and economic co-benefits are associated with reductions in fossil fuel combustion.

The set of studies underlines the importance of health co-benefits from an environmental intervention that is based on energy policy decision-making, as demonstrated in this study.

ACKNOWLEDGEMENTS

We would like to thank Camila Nascimento Monteiro, Julia Affonso Cavalcante and Luiza Perez Schreemp for their assistance with this research and for their comments, which greatly improved the manuscript.

FUNDING

The APROBIO (Associação dos Produtores de Biodiesel, or Association of Biodiesel Producers) provided financial support to the Health and Sustainability Institute non-governmental organization to conduct the study. The institute was responsible for the management, research and writing. The authors Paulo Saldiva and Evangelina Vormittag did not receive any grants for their participation in the study. The sponsor proposed the study and participated in the study design, suggesting the quantity of biodiesel in diesel additions and the future projections. However, the sponsor did not have any role in the collection, analysis and interpretation of data, the writing of the report or article, or the decision to submit the article for publication.

REFERENCES

Adar, S.D., D'Souza, J., Sheppard, L., Kaufman, J.D., Hallstrand, T.S., Davey, M.E., Sullivan, J.R., Jahnke, J., Koenig, J., Larson, T.V. and Liu, L.J. (2015). Adopting clean fuels and technologies on school buses. Pollution and health impacts in children. *Am. J. Respir. Crit. Care Med.* 191: 1413–1421.

Barnwal, B.K. and Sharma, M.P. (2005). Prospects of biodiesel production from vegetable oils in India. *Renewable Sustainable Energy Rev.* 9: 363–378.

Cançado, J.E., Saldiva, P.H., Pereira, L.A., Lara, L.B., Artaxo, P., Martinelli, L.A., Arbex, M.A., Zanobetti, A. and Braga, A.L. (2006). The impact of sugar cane-burning emissions on the respiratory system of children and the elderly. *Environ. Health Perspect.* 114: 725–729.

Companhia Ambiental do Estado de São Paulo (2014). Qualidade do ar no estado de São Paulo 2013. CETESB, São Paulo. http://ar.cetesb.sp.gov.br/publicacoes-relatorios/, Last Access: 13 January 2016.

Eliasson, J., Hultkrantz, L., Nerhagen, L. and Rosqvist, L.S. (2009). The Stockholm congestion - charging trial 2006: Overview of effects. *Transp. Res. A* 43: 240–250.

Finlayson, G.S., Stewart, D., Tate, R.B., MacWilliam, L. and Roos, N. (2005). Anticipating change: how many acute care hospital beds will Manitoba regions need in 2020? *Can. J. Aging* 24: 133–140.

Giakoumis, E.G., Rakopoulos, C.D., Dimaratos, A.M. and Rakopoulos, D.C. (2012). Exhaust emissions of diesel engines operating under transient conditions with biodiesel fuel blends. *Prog. Energy Combust. Sci.* 38: 691–715.

Goodman, P.G., Rich, D.Q., Zeka, A., Clancy, L. and Dockery, D.W. (2012). Effect of air pollution controls on black smoke and sulfur dioxide concentrations across Ireland. *J. Air Waste Manage. Assoc.* 59: 207–213.

Haines, A., McMichael, A.J., Smith, K.R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B.G., Campbell-Lendrum, D., Dangour, A.D., Davies, M. and Bruce, N. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: Overview and implications for policy makers. *Lancet* 374: 2104–2114.

Hamra, G.B., Guha, N., Cohen, A., Laden, F., Raaschou-Nielsen, O., Samet, J.M., Vineis, P., Forastiere, F., Saldiva, P., Yorifuji, T. and Loomis, D. (2014). Outdoor particulate matter exposure and Lung cancer: A systematic review and Meta-analysis. *Environ. Health Perspect.* 122: 906–912.

Henschel, S., Atkinson, R., Zeka, A., Le Tertre, A., Analitis, A., Katsouyanni, K., Chanel, O., Pascal, M., Forsberg, B., Medina, S. and Goodman, P.G. (2012). Air pollution interventions and their impact on public health. *Int. J. Public Health* 57: 757–768.

Hou, Q., An, X.Q., Wang, Y. and Guo, J.P. (2010). An evaluation of resident exposure to respirable particulate matter and health economic loss in Beijing during Beijing 2008 Olympic Games. *Sci. Total Environ.* 408: 4026–4032.

Instituto Brasileiro de Geografia e Estatística (2013). Projeção da população das unidades da federação por sexo e idade: 2000-2030. IBGE, Rio de Janeiro.

Interacademy Medical Panel (2010). Statement on the health co-benefits of policies to tackle climate change. http://www.interacademies.net/Resources/14589/14745.aspx, Last Access: 13 January 2016.

Johansson, C., Burman, L. and Forsberg, B. (2009). The effects of congestions tax on air quality and health. *Atmos. Environ.* 43: 4843–4854.

Kelly, I. and Clancy, L. (1984). Mortality in a general hospital and urban air pollution. *Ir. J. Med.* 77: 322–324.

Nichols, A. Maynard, V., Goodman, B. and Richardson, J. (2009). Health, climate change and sustainability: A systematic review and thematic analysis of the literature. *Environ. Health Insights* 3: 63–88.

Ostro, B. (2004). *Outdoor air pollution: Assessing the environmental burden of disease at national and local levels*. WHO Environmental Burden of Diseases Series. World Health Organization, Geneva.

Patz, J.A., Frumkin, H., Holloway, T., Vimont, D.J. and Haines, A. (2014). Climate change: Challenges and opportunities for global health. *JAMA* 312: 1565–1580.

Pinto, A.C., Guarieiro, L.L.N., Rezende, M.J.C., Ribeiro, N.M., Torres, E.A., Lopes, W.A., Pereira, P.A.P. and Andrade, J.B. (2005). Biodiesel: An overview. *J. Braz. Chem. Soc.* 16: 1313–1330.

Pope, C.A. (1989). Respiratory disease associated with community air pollution and a steel mill. *Am. J. Public Health* 79: 623–628.

Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K. and Thurston, G.D. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J. Am. Med. Assoc.* 287: 1132–1141.

Pope, C.A., Burnett, R.T., Thurston, G.D., Thun, M.J., Calle, E.E., Krewski, D. and Godleski, J.J. (2004). Cardiovascular mortality and long-term exposure to particulate air pollution: Epidemiological evidence of general pathophysiological pathways of disease. *Circulation* 109: 71–77.

Pope, C.A., Schwartz, J. and Ransom, M.R. (1992). Daily mortality and PM_{10} pollution in Utah Valley. *Arch. Environ. Health* 47: 211–217.

Ransom, M.R. and Pope, C.A. (1992). Elementary school absences and PM_{10} pollution in Utah Valley. *Environ. Res.* 58: 204–219.

Rodrigues, C.G., Andrade, M.V., Queiroz, B. and Machado, C.J. (2013). The applicability of the Lee-Carter method to forecast health services use in Brazil. In *Applied Demography and Public Health*, third ed. Hoque, N., McGehee, M.A. and Bradshaw, B. (Eds.), Springer, Netherlands, pp. 371–385.

Rodrigues, C.G., Vormittag, E.dM. P.A., Cavalcante, J.A. and Saldiva, P.H.N. (2015). Projeção da mortalidade e internações hospitalares na rede pública de saúde atribuíveis à poluição atmosférica no Estado de São Paulo entre 2012 e 2030. *Rev. Bras. Estud. População* 32: 489–509.

Sánchez-Ccoyllo, O.R., Ynoue, R.Y., Martins, L.D. and de Fátima Andrade, M. (2006). Impacts of ozone precursor limitation and meteorological variables on ozone concentration in São Paulo, *Brazil. Atmos. Environ.* 40: 552–562.

Tonne, C., Beevers, S., Armstrong, B., Kelly, F. and Wilkinson, P. (2008). Air pollution and mortality benefits of the London congestion charge: Spatial and socioeconomic inequalities. *Occup. Environ. Med.* 65: 620–627.

Tonne, C., Beevers, S., Kelly, F.J., Jarup, L., Wilkinson, P. and Armstrong, B. (2009). An approach for estimating the health effects of changes over time in air pollution: An illustration using cardio-respiratory hospital admissions in London. *Occup. Environ. Med.* 67: 422–427.

United States Environmental Protection Agency (USEPA) (2015). The Clean Air Act and the economy, http://www.epa.gov/clean-air-act-overview/clean-air-act-and-economy, Last Access: 13 January 2016.

Wang, W., Primbs, T., Tao, S. and Simonich, S. (2009). Atmospheric particulate matter pollution during the 2008 Beijing Olympics. *Environ. Sci. Technol.* 43: 5314–5320.

Woodcock, J., Edwards, P., Tonne, C., Armstrong, B.G., Ashiru, O., Banister, D., Beevers, S., Chalabi, Z., Chowdhury, Z., Cohen, A. and Franco, O.H. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: Urban land transport. *Lancet* 374: 1930–1943.

World Health Organization (WHO) (2006). Air Quality Guidelines-Global Update. WHO, Copenhagen. http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf, Last Access: 13 May 2016.

World Health Organization (WHO) (2015a). Health and the environment: Addressing the health impact of air pollution. Draft resolution proposed by the delegations of Albania, Chile, Colombia, France, Germany, Monaco, Norway, Panama, Sweden, Switzerland, Ukraine, United States of America, Uruguay and Zambia. 2015. Sixty-Eighth World Health Assembly. http://apps.who.int/gb/ebwha/pdf_files/WHA68/A68_ACONF2Rev1-en.pdf, Last Access: 13 May 2016.

World Health Organization (WHO) (2015b). World Health Organization key messages for COP21. http://who.int/globalchange/mediacentre/events/cop21-key-messages/en/, Last Access: 13 May 2016.

Received for review, November 1, 2017
Revised, March 1, 2018
Accepted, March 3, 2018