Economic Valuation of Vehicular Emissions in Deployment of Bus Rapid Transport (BRT) System

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***Abstract*— This paper aims to economically valuate the variation in vehicular emissions from a Bus Rapid Transit (BRT) system, which are estimated based on the variations they cause in hospitalization costs and working days lost due to diseases related to air pollution. Therefore, the International Vehicle Emission (IVE) model was used to estimate the emissions. For the economic valuation of vehicular emissions the chosen method was the method of marginal productivity. This method allows the use of a function that represents the relationship between pollution and the consequences on the health of the affected population. It also allows the use of an economical model that enables the calculation of monetary values that result from this relationship. This paper used the corridor BRT Transcarioca as a case study, deployed in the city of Rio de Janeiro. The economic valuation presented the expenses with public health and the decrease in productivity due to diseases related to pollution, generating an economy of R$ 14,396,277.85 per year by reducing these morbidities. This reinforces the importance of the BRTs systems as a transport alternative in the cities, not only to improve urban mobility, but also to promote important gains by reducing expenses with health.**

***Index Term*— BRT, economic, emissions, health, valuation.**

I. INTRODUCTION

THIS paper aims to economically valuate the variation in vehicular emissions from a Bus Rapid Transit (BRT) system, which are estimated based on the variations they cause in hospitalization costs and working days lost due to diseases related to air pollution. Therefore, this study serves as a tool to assist the public administrators in the decision-making process of urban mobility and environmental health. Therefore, the object of this study is the environmental impact caused by the deployment of the BRT Transcarioca in the city of Rio de Janeiro, Brazil. The International Vehicle Emission (IVE) model was used to estimate the emissions; also a methodology to apply this model in BRT systems was developed. After determining quantitative values, vehicular emissions calculations were estimated in two situations: “before” and “after” the implementation of the corridor BRT Transcarioca. The calculations considered a 5% reduction in the number of cars due to modal shift.

According to [8], in 2009 the vehicular emissions – mobile sources – were responsible for 77% of total air pollutants emitted in the Metropolitan Region of Rio de Janeiro. It also informs that these sources contribute to 98% of Carbon Monoxide (CO) emissions, 67% of Hydrocarbons (HC) emissions, 37% of Nitron Oxide (NOx) and 42% of Particulate Matters (PM) [8].

These emissions affect the expenses of health care by increasing the occurrence of respiratory and cardiovascular diseases, especially among the most vulnerable groups, which are children under 5 years old and elderly over 65 years old. Besides that, they cause economic losses by reducing the productivity of the economically active population.

Aiming to decrease the vehicular emissions, besides improving urban mobility, an alternative that has been adopted in different countries such as Brazil, Colombia, Mexico, United States, Japan and France are the deployment of systems that are designed based on exclusive corridors for high capacity buses, called BRT [1].

The BRT system has a great potential of reducing emissions in urban areas, considering that the bus rides correspond to approximately 85% of the public rides in Brazilian cities. Compared to the conventional bus systems, the BRT can transport a greater quantity of passengers; therefore, it reduces the consumption of fuel per passenger and per kilometer. Since the BRT vehicles use exclusive roads, they present a higher average speed, resulting in a better service and in fewer emissions [2].

This paper is arranged in sections: Section I corresponds to introduction; Section II presents the different methodologies for economic valuation of vehicular emissions and an argument for the chosen model; Section III presents the economic valuation developed for the BRT Transcarioca; and it ends with the conclusions of this study.

II. ECONOMIC VALUATION METHODOLOGIES OF VEHICULAR EMISSIONS

The methods of economically valuing the environment are part of the microeconomic theoretical framework of the well-being and are needed for the evaluation of the costs and social benefits whereas the public investments decisions affect the population consumption and, therefore, its well-being.

The choice of one or other methods of economically valuing the environment depends on the objective of the valorization, the hypothesis considered, the availability of data and the scientific knowledge related to the ecological dynamic of the subject.

According to [14], the methods of valuation are classified

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as:

- Methods of demand function:
  - Methods of market of complementary goods (hedonic prices and travel cost);
  - Methods of contingent valuation.
- Methods of production function:
  - Method of substitute goods.
  - Method of marginal productivity.

The method of marginal productivity was the chosen method, since it was better applied to the problem of valuation of health impacts caused by vehicular emissions. This method allows the use of a function that represents the relationship between a pollution dose and the response from the polluted or degraded environment asset. It also allows the use of an economical model that enables the calculation of monetary values that result from this relationship.

III. Economic Valuation - Case Study BRT Transcarioca

The purpose of this stage is to calculate how much the government can save in health care expenses due to the decrease in pollutants emissions using BRTs systems. More specifically, the main goal is to estimate the gains obtained through the deployment of the corridor BRT Transcarioca.

The BRT consists in a bus transit system that provides fast, comfortable and cost-effective services, improving urban mobility [9].

This study is considering the hypothesis that only the population that lives in the region of influence of the project is being affected by the variations in vehicular emissions from the installation of the corridor. This hypothesis may be conservative, once it does not consider the population living in the neighboring areas, which also might be affected due to the dispersion of the pollutants, as well as the population that does not live in the considered area of study but works or studies there.

A. Estimative of Vehicular Emissions

Typically, emissions from mobile sources are quantified through computational models, which have been developed in North America and Europe. These models are based on fuel specifications, types of vehicles, driving patterns, monitoring and maintenance programmes, and climate features [3], [5], [6].

The International Vehicle Emission (IVE) model was chosen in this paper because it is a dynamic model; it was designed to estimate emissions especially in developing countries; moreover, its database was built in the city of São Paulo, hence, this model has been shown to be adequate for use in projects deployed in Brazilian cities. The IVE model was developed by the International Sustainable Systems Research Center (ISSRC) and by the University of California, Riverside, and funded by the U.S. EPA [13]. This model estimates the emissions of a range of pollutants, such as CO, HC, NOx, CO_2 and Methane (CH4), considering passenger cars, motorcycles, trucks and buses. Another favorable factor leading to its choice is how this model is available for free on the internet and contains an accessible channel to technical support. Besides that, it was the best-rated model on researches, presenting the most friendly interface among all evaluated models in the same research [11].

The Table I below shows a comparative summary between the emissions produced in the "before" and "after" situations of the deployment of the system considering the hypothesis of occurring 5 % of migration of the vehicle users to the BRT system, highlighting the decrease in emissions. The decrease in pollutants emission, besides decreasing 5 % in vehicle users, contributes to the decrease in the number of buses, and to its improvement in operational systems and modernity.

TABLE I
IMPACTS ON HOSPITALIZATION

Total	**CO (g/km)**	**VOC (g/km)**	**NO_x (g/km)**	**SO_x (g/km)**	**PM (g/km)**	**CO_2 (g/km)**
Before the Corridor	125,482.2	16,182.8	33,893.5	709.8	3,317.4	4,386.3
After the Corridor	113,657.5	13,982.0	21,358.9	596.7	1,260.6	3,862.7
Variation (After - Before)	-11,824.7	-2,200.8	-12,534.6	-113.1	-2,056.9	-523.5
Reduction (%)	9.4	13.6	37.0	15.9	62.0	11.9

B. Economic Valuation

To estimate the potential impacts on the population's health in the considered area of influence of the project, and by considering the reduction in emission of particulate matter (PM10) estimated in the previous section, the methodology used was the one developed by The World Bank [10]. This methodology has analyzed studies available in literature about the relationship between the occurrences of changes in pollution levels and their impacts on the population health. Since the majority of these studies were done in developed countries, their results were verified to enable further estimation in developing countries, which have difficulties in developing wide-ranging and reliable databases to their own studies. The results were applied in six different cities, among them are Mumbai, India and Santiago, Chile, both receiving satisfactory outcomes.

In order to estimate the economic value associated with the variation of pollution levels and impacts on population health, four factors were analyzed: the dose-response relationship, the most susceptible population to the pollution changes, the relevant change in air pollution, and an economic examination of the health care expenses.

The first step is to estimate the effects of air pollution on various aspects of health. Dose-response functions, which relate various health results to the changes in air pollution, are taken after the revision of epidemiologic literature. These functions allow the estimation of changes in health, which would be expected from the alterations in air pollution levels. For each health effect, one range is presented within which the estimated effect which will probably be framed. The central estimate used is typically selected from the center of the described range in a certain study, or it is based on the most recent study using the most trustable estimative methods that are available. When studies are available to a certain effect on health, the range reflects the variation on the observed results of these studies.

The reported epidemiological investigations involve two main study models: statistic interference based on temporal series and transversal data sets. The analysis of temporal series analyzes changes in aspects of health within a specific area, with air pollution levels varying through time. The transversal analysis compares the rate or prevalence of certain health outcomes in different places at a certain point in time. The studies of time series have the advantages of reducing or eradicating the problems associated with confounding or omitted variables, a common concern in transversal studies. Since the characteristics of the population are basically constant through the period of study, the only factors capable of changing with the daily mortality are the environment and weather conditions. In general, the researchers are capable of extracting more easily the effects of air pollution and weather over health in the studies of time series. Therefore, the review of the methodology developed by the World Bank focused mainly on studies of temporal series. However, the use and extrapolation of results from the time series analysis are based on their applicability to other areas and to other time periods.

By using the results of time series from the countries, the relationship between variation in pollution and health aspects, such as premature mortality, hospitalizations, acute respiratory symptoms, bronchitis in children, etc., can be estimated.

To provide an estimative of changes in the prevalence of a certain health effect associated to a variation in the amount of emission of a given pollutant, it was calculated the partial derivative (or inclination, b) from the Dose-Response function.

In the next stage, the parameter b from the Dose-Response function is multiplied by the population that is believed to have been exposed to the pollutants or that is susceptible to the air pollution effect analyzed. For certain pollution effects on health, the entire exposed population may be considered in calculation, whereas to other effects there might be more sensible subgroups, such as children or asthmatics.

A third step in calculations of air pollution effects in health involves the multiplication of what was calculated in the previous stage by the observed changes in air quality.

For the variation in the PM10 pollutant concentration the methodology is synthetized by the equation below:

$$\Delta S = b * \Delta C * P \quad (1)$$

Where:
ΔS is the health impact;
b is the partial derivative of the dose-response function;
ΔC is the variation in the PM10 pollutant concentration;
P is the exposed population to such concentration.

Even though the obtained results are important indicators of the lack of more precise results, they may be seen as general estimative of air pollution impacts. This is due to the deficiency of air quality monitoring coverage in developing countries, and the use of temporal series data to obtain the Dose-Response function from countries which have distinct social and economic characteristics from the places where the data are being applied.

In the equation (1) presented above the variation in the concentration of particulate matters is applied. The relationship between the concentration and emission is complex and requires a research work. As a primary simplification, in this paper it will be considered a linear and proportional correlation between the variables of emission and concentration, which means the PM10 concentration will decrease in the same proportion as the pollutant emission.

According to [8], in the Taquara Station, placed in the area of influence of the studied project, the annual concentration of particulate matter – PM10 (μg/m³) measured in 2009 was approximately 16 μg/m3.

Considering that the reduction in the particulate matter concentration will be proportional to its estimated emission, there is a reduction of 9.92 μg/m3, which corresponds to 62% of the 16 μg/m3 measured in the Taquara Air Quality Monitoring Station.

According to the Socioeconomic Studies Report of the case study, the set of traffic zone of the area of influence had a population of 621,020 inhabitants in the year 2000, according to the 2000 Brazilian's Census carried through by the Brazilian Institute of Geography and Statistics (IBGE) [12]. This will be the data used in the calculation of health impact; therefore the obtained result will be reveled conservative, since the same report already pointed an increase of the referred population to 633,000 inhabitants in the year 2004, in case the estimated rates from the last decade were maintained.

1) Hospitalization due to Respiratory Problems

According to [10], to estimate the hospitalization rates due to respiratory problems, the parameter b is equal to 0.000012, which indicates that if the particulate matter concentration decreases in 1 microgram per cubic meter, there will be a decrease of 1.2 hospitalizations in a sample of one hundred thousand inhabitants. The calculated variation in concentration is equal to 9.92 μg/m³. Finally, the exposed population is the one from the area of influence of the project, 621.020 inhabitants [12].

Through this methodology, it was obtained a total of 74 avoided hospitalizations per year (ΔS). This number is multiplied by the average cost of each hospitalization due to respiratory problems, R$ 994.30 [4], resulting in the avoided average cost of R$73,578.20, as shown in the Table II below. This result refers to one of the social benefits generated by the deployment of the studied BRT system.

TABLE II
IMPACTS ON HOSPITALIZATIONS

Reduction (concentrations)	Reduction (hospitalizations)	Cost of hospitalization	Cost
9.92 μg/m³	74	R$ 994.30	R$ 73,578.20

2) *Working Days Lost*

Working days lost are defined as those in which people do not attend to their working places due to problems related to air pollution. Those problems vary from indisposition to hospitalization due to cardiovascular or respiratory problems. When people go to the doctor's office or are hospitalized, they sacrifice working days that would generate incomes, which represents a cost to society.

The developed methodology by The World Bank allows the estimative of how many days lost are due to the concentration of particulate matter [10]. For this purpose, the same formula from the previous section was used, but with the parameter b equal to 0.0575, which indicates that if the concentration of particulate matter decreases in 1 microgram per cubic meter, there will be a decrease of 5,750 working days lost per year in a sample of one hundred thousand adults.

According to the 2010 Brazilian's Census, the population of the city of Rio de Janeiro is 6.320.446 inhabitants, among them 4.174.528 are adults between 20 and 69 years old [7]. Therefore, if the same proportion is maintained in the area of influence of this studied project, there are 410,494 adults in that area.

Through the application of the methodology, the result was 234,145 working days lost per year that could be avoided. The estimated cost per working loss day was calculated based on the average monthly income of R$ 1.835,20 for the city of Rio de Janeiro [7]. This value divided per 30 results in an average daily income of R$ 61,17. As the Table III below shows, the avoided average cost obtained by performing the calculation was R$ 14.322.649,65 per year.

TABLE III
IMPACTS ON COSTS DUE TO WORKING DAYS LOST

Reduction (concentrations)	Reduction (days lost)	Cost of days lost	Cost
9.92 μg/m³	234,145	R$ 61,17	R$ 14.322.649,65

Although the number of days lost that could be avoided seems to be very large, when compared to the adult population in the same region the rate obtained is 0.57 day/adult. This reduction in particulate matter emission would avoid, for instance, a visit to the doctor's office due to respiratory problems, per adult once a year. That would be enough to generate the economy of all quantitative previously calculated.

IV. CONCLUSION

To define the method of economically valuing to be used, the main existing methods were analyzed. The marginal productivity method was chosen, since it was better applied to the problem of valuation of health impacts caused by vehicular emissions.

This method has been shown adequate since it allows the combination of two different stages: the physic function, which represents the relationship between the pollution dose and the response from the variation in mortality or morbidity of the affected population; and the economic model and its application, which allows the calculation of monetary income of this relationship.

The lack of data of pollution concentrations in the area of influence of the project, which reflects the variations resulted by the deployment of this system, inhibits the development of a dose-response function that relates these concentrations to the variation in the number of hospitalizations due to respiratory diseases in the affected area. Hence, the dose-response function elaborated by the World Bank was used. This function estimated the reduction of R$ 73,578.20 in expenses with hospitalizations per year, and the cost saving of R$ 14,322,649.65 per year of working days lost due to respiratory problems.

It should be highlighted that these values are only an indicative, because they were obtained through a dose-response function, which does not represent the reality in the studied area. Moreover, different factors interfered in the result, such as the dispersion of emitted pollutants, the weather and the geography of the area.

The deployment of BRTs systems may be adopted by the public administrators, not only because it is an important alternative to improve urban mobility, but also to promote an economy with expenses with diseases caused by vehicular emissions, improving life quality of the population and providing environmental gains.

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