Economic and Environmental Valuation Applied to Air Quality Management and Pollution Control Cases

Report for the Regional Policy Dialogue of the Inter-American Development Bank

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Introduction

During the last decades civic rights and obligations have been established, government functions and public organizations responsible for environmental issues have been defined, progress has been made in the formulation and application of environmental policies, and instruments and strategies for environmental protection have been developed. In spite of the recorded progresses, important pollution problems still persist as well as the destruction and degradation of the environment and renewable resources. These processes bring negative consequences for the economic development of countries and affect the quality of life of the citizens, especially of the poorer ones.

Developing countries need to evaluate the possible uses of their scarce resources for public expenses and private investments concerning sustainable development. This is why it is important to have the ability to assess the costs of the degradation of natural resources from an economic standpoint and from an environmental perspective. A better understanding of the economic costs of environmental degradation might facilitate the evaluation of policies for the protection and improvement of the environment and at the same time support more specific objectives.

Objectives

The main objective of this report is to provide relevant information to improve the decision-making process regarding air quality and pollution control. The specific goal is to create a review report regarding experiences in the matter of air quality valuation and pollution control, covering the most relevant analytical and methodical aspects in the estimation of economic and environmental benefits. The use of economic analysis in relation with air quality is an important example of the environmental-economic valuation, given the significant impact that air pollution can have on health and mortality, as well as on other social interests (material damage, decrease in agricultural production, and damage to natural resources).

Conceptual framework

A decrease in air quality produces several impacts on health: some are short term such as nasal irritation, ocular irritation; others with more significant consequences such as chronic bronchitis and, lastly, an increment of premature death risks. The population perceives only some of these effects immediately and links them to air pollution, however, hardly ever relates a decrease in life expectancy with the quality of air. Poor air quality produces negative effects on the urban visual aesthetics as well, this being either by the decrease of visibility or by the particles accumulation in the buildings' exterior, thus creating a feeling of a degraded environment. From the productive standpoint, the quality of air affects the yield of some crops, increases the frequency in which buildings' exteriors need to be restored, impacts the maintenance of certain civil works, and degrades tourist attractions. All of these effects involve important economic losses that are usually ignored in market transactions and national account systems.

Atmospheric pollution originates from economic activities that emit pollutants at a higher rate than the atmosphere is naturally able to remove. Given the fact that the emission of these pollutants does not represent a cost for those who emit them (or it might even signify savings), the economic agents do not have any incentives to reduce them. Hence, it is possible to ask oneself if an atmospheric pollution control policy would generate net social benefits; if the benefits from pollution reduction surpass the costs. The pollution control management is proportional to the reduction amount in pollutants' concentration necessary to promote social welfare. For this, the economic valuation methods specifically calculate the *marginal* benefits associated with a better air quality. In the same way, the methods calculate the costs to maximize the improvement in air quality. Unfortunately, although this is easy from a theoretical point of view, it is complex in terms of practical purposes. The reason is that a big part of the benefits are generated outside the market and thus, it is necessary to use indirect information in order for these to be evaluated.

Estimation of benefits associated with a better air quality

For some types of damages it is relatively easier to estimate the marginal damages. For example, it is possible to determine how a change in the amount of pollution affects the yield of crops. In this particular case, the physical impact would be given by a final product reduction. In both cases, the valuation of these impacts is immediate: it is enough to know the market price to calculate the economic loss. In other cases, however, it is more complex to calculate marginal damages – specifically, health damages.

The *function damage method* consists in the use of sequential models to determine the physical impacts of pollution, and in economic models to calculate the value of these impacts. In one hand, one resorts to epidemiological or physical models to determine the effect that a change in pollutants concentration has on the health of the populace, visibility, material damage and in vegetation. Once some of these impacts have been quantified, one proceeds to translate these into monetary terms using different valuation techniques. These methods can include cost measurements (like medical attention costs or income loss due to a work disability caused by a pollution related disease); indirect indicators such as fluctuations in real estate prices attributable to the environmental quality, or methods like surveys, that try to find direct information about the population's willingness to pay for an improvement of environmental quality. The use of this method is the way chosen in the majority of the studies that have estimated the benefits of atmospheric pollution reduction.

Information and capabilities requirements

To estimate the benefits of atmospheric pollution reduction, the basic tools required are an inventory of emissions and meteorological data. Regarding the former, it is necessary to have an account of the generated emissions for each type of source of the most important primary pollutants. This stage requires advance knowledge in the modeling of the activity levels for each source and its emission factors. Ideally, these emission factors should be determined locally but, considering the complexity and costs of doing this, many times emission factors derived from other countries are used.

For the economic valuation it is required to know the monetary costs for each one of the determined effects. These values may be obtained through the human capital method or using the willingness to pay method.

A government's proactive role in pollution control requires promoting the training of professionals with the knowledge described above as well as an adequate investment in facilities and equipment.

Cases of application of economic valuation of air quality

In 1991, the European Commission started the ExternE Project (http://externe.jrc.es). Its objective was to measure in a detailed manner, the external costs associated with the different fuel cycles. It has been already applied in several European countries such as Germany, Belgium, Spain, Finland, France, Greece, and the United Kingdom. For example, the potential emissions' reduction if electric vehicles are introduced was analyzed in Paris. It was calculated that non-internalized costs represent close to 4% of a gasoline-fueled car's cost and a 70% of diesel vehicles. If this costs were internalized it is concluded that the price of electric cars would be competitive against diesel vehicles but not against gasoline-fueled ones.

Up until present time in the United States, the USEPA has prepared two cost and benefits analysis of the Clean Air Act, one retrospective for the 1970-1990 period [EPA 1997], and another prospective for the 1990 – 2010 period [EPA 1999]. Both studies are based on the damage function method, using only studies developed in the United States.

In several Latin-American countries (such as Chile, Ecuador, Mexico, and Peru), the legislation explicitly requires the development of technical and economic studies when dictating norms of atmospheric pollution control. In others, even though the legislations might not be very specific in terms of considering this obligation, these sorts of studies are in fact prepared in a public, unconcealed way.

Case Study 1: Estimation of benefits, Prevention and Environmental Decontamination Plan of the Metropolitan Region (PEDP), Santiago de Chile

The actual Chilean environmental legislation requires the elaboration of economic and social impact studies in the creation of prevention and environmental decontamination plans and in the establishment of norms regarding the pollutants emission. The legislation does not establish which particular use may be given to a study; from this it can be implied that these are a tool in the search for more efficient solutions and in the dissemination of information to the entire community.

In the year 1997 the first Prevention and Environmental Decontamination Plan (PEDP) for the Metropolitan Region of Santiago de Chile was prepared, as a result of a confirmation that the zone was saturated with four atmospheric pollutants. The Plan consisted in identifying the activities and sources of pollutants emissions and elaborating emission reduction strategies for each group of activities in order to comply with the established goals for the year 2011 in terms of air quality.

The most important direct benefits of the PEDP pertain to human health improvements, particularly a decrease in premature death risk and the possibility of suffering respiratory diseases. Other considerable direct benefits are a result of material damage reduction, a rise in agricultural productivity, the decrease of critical episodes, and an increase in visibility. For another part, there will also be important indirect benefits associated with shorter travel times, savings in fuel usage, an increase of green areas, and the extension of environmental education. These benefits are detailed in Table 1 distinguishing the ways in which these favor the different social sectors, the population, the emitters, and the Government.

Table 1 Quantified benefits generated by the PEDP for the population, emitters, and the Government (US$)

Benefit	Population	Emitters	Government	Total
Human health	392,172,150	0	74,767,355	466,939,505
Materials	445,053,991	0	0	445,053,991
Agriculture	0	143,740,000	0	143,740,000
Critical episodes	0	37,597,029	2,285,255	39,882,284
Quantified totals	837,226,141	181,337,029	77,052,610	1,095,615,780

Source: [CONAMA R.M. 1997]

In order for these benefits to become a reality, it is necessary for the emitters and the government to contribute with important costs. According to the contents evaluated in this analysis, the necessary costs for the application of the PEDP amount up to at least US$ 911,230,711, out of which 47.6% are absorbed by the emitters and 52.4% by the Government. Table 2 details the costs required for the application of the PEDP. Similarly to the case of benefits, the total costs of the PEDP exceed the ones quantified in this analysis. This way, the values showed in Table 7 should be interpreted as minimum indicators of the total benefits and PEDP costs. Finally, the Benefit/Cost ratio reaches 1.2

Table 2 Quantified Costs for the Implementation of the PEDP (US$)

	Emitters	Government	Totals
Transportation	300,261,383	163,984,218	464,245,601
Industry, commerce and construction	51,435,857	26,071,250	77,507,107
Agriculture	268,824	1,121,003	1,389,827
Domestics	-52,253,008	0	-52,253,008
Re-Suspended particles	0	119,617,550	119,617,550
Extrapolation	134,198,998	139,160,592	273,359,589
Subtotal	433,912,053	449,954,613	883,866,666
Environmental education	0	10,336,884	10,336,884
Follow up	0	17,027,161	17,027,161
Subtotal	0	27,364,045	27,364,045
TOTAL COSTS	433,912,053	477,318,658	911,230,711
TOTAL BENEFITS	181,337,029	77,052,610	1,095,615,780
BENEFITS / COSTS	<1	>1	1,20

In the year 2000 the benefits of the PEDP were re-estimated based on new scientific evidence and with some methodology changes. In Table 3, it can be seen the estimation of benefits and costs of the PEDP for the 2000-2005 period. As a result of using the willingness to pay method, the health benefits have increased significantly: these represent 91% of the total benefits. The rest of the benefits are from fewer damages to construction material and from better visibility. In this estimate, the Benefit/Cost ratio rises to 5.9

Table 1 Benefits and Costs 2000 – 2005 PEDP (US$ in millions)

Benefits	**Emitters**	**Government**	**Population**	**Total**
Industry, commerce, and homes	0	39	304	343
Transportation and fuels	0	44	344	388
Suspended dust	0	2	47	49
TOTAL BENEFITS	0	85	695	780
Costs	**Emitters**	**Government**	**Population**	**Total**
Industry, commerce, and homes	4	0	0	4
Transportation and fuels	103	0	0	103
Suspended dust	0	26	0	26
TOTAL COSTS	107	26	0	133
NET SOCIAL BENEFIT	-107	59	695	647
BENEFIT/COST				5,9

Source: [CONAMA R.M. 2001]. Note: All numbers are rounded off to two significant figures

Case Study 2: Economic valuation of air quality improvement in the Metropolitan Zone of the Valley of Mexico.

This Program was created by the Metropolitan Environmental Commission with the purpose of protecting the population's health and reducing the number of environmental emergencies in the Metropolitan Area of the Valley of Mexico. The study considers a reduction in the concentration levels of two environmental pollutants: ozone (O_3) and particulate matter (PM10). To achieve this decrease, the Program proposes a series of steps destined to the emission reduction of the primary pollutants PM10, Nitrogen Oxide (NO_x) and Volatile Organic Compounds (VOC)[1].

The results of the program are sensitive to the transfer elasticity value used, but they are more sensitive to the different parameters considered in the valuation. For example, for the 10% reduction scenario, using an elasticity of 1.0, one can see that the benefits associated with a PM_{10} reduction vary from almost 1.500 million dollars per year if one considers the willingness to pay to valuate mortality and morbidity effects, to only 158 million, if only the costs of diseases and productivity loss are considered. A large part of the benefits comes from the willingness to pay to reduce death risks. This phenomenon occurs in all the analyzed studies.

[1] The PM10 and NO_x are primary pollutants precursors of PM10, and the VOC of O_3.

Another air quality study in the Metropolitan Area of Mexico City, entirely prepared by experts in atmospheric sciences, human health economy, political science and sociology, estimated that the annual benefits of a 10% reduction of PM10 and O_3 levels in the Metropolitan Area of Mexico City would be as follows:

Table 2 Social Value of the benefits from a 10% reduction of PM10 and O_3 levels in the Metropolitan Zone of the Valley of Mexico

Effects	Reduction of Effects (cases/year)	Unit Value (US$ / case)	Social Value (US$ in Millions / year)
Mortality (PM10)	3,000	650,000	1 650
Chronic Bronchitis (PM10)	10,000	34,000	340
Total benefits PM10			**2 000**
Mortality (O3)	300	650,000	200
Restricted activity days (O3)	2,000,000	6	10
Total benefits O3			**200**
Total benefits			**2 200**

Source: Molina y Molina (2002), Tables 4.8 y 4.9

Case Study 3: The economic impact of PROCONVE on health effects caused by Atmospheric Pollution in Sao Paulo, Brazil: A results transfer exercise

The study had as an objective to estimate the benefits of a morbidity and mortality reduction generated by the amelioration of air quality due to the implementation of the third phase of the Program of Control of Atmospheric Pollution from Mobile Sources (PROCONVE) in Sao Paulo, began in 1997. This program consists in the establishment of maximum emission limits for different kinds of vehicles.

The valuation was prepared based in results transfer. To valuate the health benefits in monetary terms, the willingness to pay method was used, transferring values estimated in the United States.

The table presents the monetary benefits from positive health effects because of PROCONVE, employing the willingness to pay values. The annual value of monetary benefits is approximately US$ 2.800 million.

Monetary values of health benefits– PROCONVE - Sao Paulo (thousands of US$ from 1999)

		Avoided events		Health benefits	
		0-2 years	> 64 years	0-2 years	> 64 years
Morbidity					
Respiratory				Transferred Prices	
Admissions	PM10	4,044	905	3,356	751
	SO2	2,524	432	2,094	358
	CO	4,530	--	3,759	--
	Totals	**11,098**	**1,337**	**9,209**	**1,109**
				Health Expenses	
	PM10	4,044	905	5,595	2,155
	SO2	2,524	432	3,492	1,029
	CO	4,530	--	6,267	--
	Totals	**11,098**	**1,337**	**15,353**	**3,184**
Mortality				Transferred Prices	
	NO2	1,420	--	819,686	--
	PM10	--	798	--	460,640
	SO2	--	-578	--	-333,647
	CO	--	3,302	--	1,906,057
	Totals	**1,420**	**3,522**	**819,686**	**2,033,051**
Total				**US$ 2,881 millions**	

Source: [Ortiz and Serôa da Motta 2002] Table 6

The table displays several interesting points. First of all, the core of the benefits is given by the willingness to pay to avoid premature death, especially for those over 65 years old. The direct health expenses associated to hospital admissions amount up to a little over 18 million dollars, a small fraction of the total of benefits.

Part I Theoretical Grounds

1. Conceptual Framework

The air quality and pollution control management problems have an extensive recorded history. A great number of regulations have been applied throughout the World during the 20th century, especially in its second half. Even when certain episodes of extreme pollution, such as Sonora, PA in USA in 1948, and London, England in 1952, had clearly shown that high pollution levels evidently had fatal effects, it was believed that only extremely high levels, such as those, could produce undesirable effects. Generally, the criterion that ruled the regulations derived from the conviction that there is a pollutant concentration level in the atmosphere below of which the effects on the person's well being, especially on the population's health, were null. This way, once the norm was achieved no additional benefit was obtained from additional reductions in the concentration levels of pollutants. However, in the last 15 years[2] new epidemiological studies have indicated the existence of important health benefits generated from the continuous reduction of pollution levels, in other words, these have shown that there is no apparent threshold below which the negative effects on the population cease to exist.

1.1 Benefits associated with an improved air quality

Poor air quality produces several impacts on health: some are short term such as nasal irritation, and eye irritation, others having more permanent effects such as chronic bronchitis episodes, and finally, an increase in the risk of suffering a premature death. The population only perceives some of these effects immediately and links them to the quality of air; however, hardly relates a decrease in life expectancy with air quality. Poor air quality also produces negative effects on the visual aesthetics in urban areas, whether because of lowered visibility and/or because of the filthiness that accumulates on the face of buildings giving the sensation of a deteriorated environment. From a productive standpoint, the quality of air reduces the yield of certain crops[4], increases the frequency

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[2] The new time series epidemiological studies begun at the end of the 80's, with studies such as the one by Schwartz and Dockery, professors of the Public Health School of Harvard University.

[3] Los nuevos estudios epidemiológicos de series de tiempo comenzaron a finales de los '80, con estudios como los de Schwartz y Dockery, profesores de la Escuela de Salud Publica de la Universidad de Harvard.

[4] In the case of sulfuric anhydrous, it affects wheat, soy, and rice primarily, while ozone primarily affects leguminous plants (source: http://www.york.ac.uk/inst/sei/rapidc2/impactscrops.html).

at which the faces of the buildings need to get cleaned, impacts on the maintenance of certain civic landmarks, increases the corrosion of metallic structures[5], and degrades touristy sites. All of these effects involve important economic losses that are frequently ignored in market transactions and national account systems.

The origin of current atmospheric pollution owes its existence to those economic activities that emit pollutants at a higher rate than the atmosphere can naturally remove. Given that the emission of these pollutants has no cost for the emitters (they could even result in savings), the economic agents do not have incentives for reducing it. The counterpart to this pollutant emission is given by the negative impacts that cause air quality. Given this, it is natural to wonder if an atmospheric pollution control policy would generate net social benefits: if the benefits from pollution reduction surpass the costs, then this policy would be beneficial from a social perspective.

The administration in charge of pollution control has to decide *in which* quantities the pollutants' concentrations must be reduced to promote social well being and, in order to do this, it is first necessary to determine the benefits (costs) associated with a better (worse) air quality. Unfortunately, even though this is simple from a theoretical standpoint, it is extremely complex to do in practical cases. Regardless of this, to make a better informed decision it is fundamental to make the effort to valuate the health benefits associated with a better air quality. It must be understood that it consists in quantifying the costs and benefits of *marginal* reductions of the current pollution levels, and not in quantifying the benefits from the total reduction of pollution: the estimation of these marginal benefits (generally associated with an air quality control program) is much less complex than the calculation of the benefit associated with the total reduction of pollution levels.

1.2 Estimation of the benefits of air quality

Why measuring the benefits associated with the amelioration of air quality is such a complex task? As it is about to be explained, this is because there are no transaction markets for concentration levels of air pollutants. If these markets existed, they would automatically become an instrument in

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[5] For more information, consult the web page: http://www.york.ac.uk/inst/sei/rapidc2/impactscorrosion.html.

[6] En el caso del anhídrido sulfuroso, afecta al trigo, soya, arroz principalmente, mientras que en el caso del ozono, afecta particularmente a las leguminosas (fuente: http://www.york.ac.uk/inst/sei/rapidc2/imp actscrops.html).

[7] Para mayor información, consultar la página web: http://www.york.ac.uk/inst/sei/rapidc2/impactscorrosion.html

[8] Véase el Anexo I para la discusión de algunos aspectos teóricos relacionadas con esta sección.

the measurement of air quality; they would indicate the costs of pollutant emissions in the atmosphere and they would force those who want to pollute to pay the costs, something impossible to do otherwise.

[9] En rigor, el daño que produce la contaminación se debe a los niveles de concentración de contaminantes; esta concentración de contaminantes está relacionada con las emisiones de contaminantes a través de la dispersión de ellos en la atmósfera. A fin de simplificar el análisis se habla del daño causado por las emisiones de contaminantes, pero se debe tener en cuenta la existencia de este proceso de dispersión: un mismo nivel de emisión de contaminantes puede generar distintos niveles de concentración dependiendo de las condiciones geográficas y meteorológicas de la zona.

[10] El costo total para la sociedad está dado por el área bajo la curva de daños marginales.

[11] El ahorro total para quien contamina está dado por el área bajo la curva de ahorros marginales.

1.3 [16]

Damage function comprises a sequence of two or more interrelated models. In the first place, there must be a model linking the pollutant concentration changes with changes in the incidence of hazardous effects on the population's health. These models are known as *dose – response* or *concentration response* functions[17]. These functions are obtained in its majority from time series, group, and transversal section epidemiological studies. The first consists in observing the temporary changes (usually daily) in the incidence of effects on a population (usually, a whole city) and statistically relate them to the changes in pollutant levels. Because the population is the same, this function serves as its own statistical control. The most important biasing effects are, in this case, the environmental variables such as temperature and humidity that, in the same way as pollution, change on a daily basis.

The transversal section studies estimate a functional relationship between the incidence of a certain effect in a metropolitan area and several variables of this, among them the pollutant concentrations for several metropolitan areas. These studies deliver an estimation of long term effects, but they are more sensitive to the specifications of the control variables.

The group studies take a sample of individuals, generally selected in a random manner, and monitor their health during long periods of time (ten or more years), relating this to individual characteristics and environmental variables. This way, they estimate the effects on the individual's health of long exposition periods to pollution. These studies require a great amount of resources, thus the shortage of them in records; except for all the ones prepared in the United States.

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[12] Enfatizamos relativamente, porque, como el lector podrá suponer, algunos pasos de esta estimación, pueden ser extremadamente complejos.

[13] Asumiendo que los impactos son pequeños, por lo que no se produce un efecto en el mercado de los productos.

[14] Sin embargo, en los últimos diez años, este conocimiento ha aumentado notablemente, como resultado de un gran esfuerzo de investigación de la comunidad internacional Holgate, S. T., J. M. Samet, H. S. Koren and R. L. Maynard, Eds. (1999). Air Pollution and Health. San Diego, Academic Press.

[15] Existen muchas maneras de formular estas preguntas, aparte de la pregunta directa, que tiene muchas limitaciones. La mas usada actualmente es enfrentar al individuo a una transacción hipotética, en la que debe solamente expresar si pagaría o no una cierta cantidad por una mejora en la calidad del aire.

[16] See Appendix I for the discussion of some theoretical aspects related to this section.

[17] The term exposition-response is also used, but we believe that the name concentration-response is more adequate given the actual use.

The health effects considered in all these studies are premature mortality and morbidity effects. The following table shows the effect for which a concentration-response ratio is available, as well as those in which the presence of an effect is suspected, but there is not sufficient evidence available.

Table 3 Health effects that have been associated with atmospheric pollution

Measurable Effects	Non Measurable Effects
Mortality (adults)	Asthma induction
Mortality (infant)	Fetal/neonatal development effects
Neonatal Mortality	More sensitivity in respiratory pathways
Bronchitis – chronic and acute	Chronic Respiratory Diseases (no bronchitis)
Asthma attacks	Cancer
Respiratory hospital admissions	Pulmonary Cancer
Cardiovascular hospital admissions	Behavioral Effects (i.e. Learning disabilities)
Emergency room visits	Neurological Disorders
Lower tract respiratory illnesses	Exacerbation of allergies
Upper tract respiratory illnesses	Alteration of defense mechanisms
Respiratory symptoms	Damage to respiratory cells
Work absenteeism days	Less time in the development of angina
Restricted activity days	Morphological changes in the lungs
	Cardiovascular arrhythmia

Source: Adapted from [EPA 1999]

Similarly to the way the health impacts of different pollutant at different concentration levels are calculated, the effects on visibility, vegetation, crops, and materials exposed to air can also be estimated. For example, visibility reductions are due primarily to the effect of light dispersion produced by particles in the range between 0.1 and 1 micron; thus the component responsible for visibility reduction corresponds to the finer fraction of the particulate matter, denominated $PM_{2.5}$. This way, by knowing how the concentration of these particles varies, the visibility levels can be determined.

The last model of the sequence is the economic valuation model, which allows putting into monetary terms the changes of health effects.

A method that has been used more frequently is the *Willingness to Pay Method* or *WTP*: it considers the maximum amount of money that the persons are willing to pay for the reduction of death risks or the probability of suffering an event affecting their health. This way, reducing the risk premature death is not valuated in terms of what is no longer produced, but in terms of the value that people assign to the reduction of death probability.

This method for calculating the monetary value of pollution-caused damages is cohesive in theory, but difficult to apply in practical cases.

Many times a physical-chemical model relating the changes in primary pollutant emissions with the changes in environmental pollutant concentrations is also included. The different pollution sources, fixed or mobile, emit primary pollutants according to a temporal and spatial pattern. These emissions become disperse in the atmosphere, subject to the effect of meteorological conditions (temperature, winds, rain, etc.) and to diverse chemical reactions (some of them due to photochemical action, subject to solar radiation), resulting in environmental pollutants concentrations. These models generally represent air quality changes in a special grid that representing the urban zone that is being studied, and perform the simulation of concentration changes for one or more "typical" days, generally for each hour of the day, and for each cell in the special grid.

This type of models can also be combined with the results obtained with direct methods, to estimate the valuation of pollutant emission reductions, and not only the valuation of the decrease in environmental concentrations.

Information and capabilities requirements

The damage function is the methodology used today to valuate the economic benefits generated by air quality improvement programs. As mentioned above, this methodology employs a wide spectrum of modeling techniques, each one requiring technical knowledge and specialized information. The book edited by Mario and Luisa Molina [Molina and Molina 2002] comprises an excellent reference in this matter; it presents an integrated approach to air quality management in the Metropolitan Zone of Mexico, and in particular, to the problem of the valuation of the quality of air.

The pollutant dispersion model requires as primary sources an inventory of emissions and meteorological data, both constructed with great detail to temporal and spatial variability, for example, as time values on a grid comprised by cells of 1×1 Km. Regarding the former, it is necessary to have the emissions generated for each type of source of the most important primary pollutants: particulate matter (PM), sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOC), and nitrogen oxides (NOx). This stage requires advanced expertise in the categorization of the activity levels of each source, and its emission factors. Ideally, these emission factors should be determined locally, but considering the complexity and costs of doing this, many times emission factors obtained from other countries are used. A good source of these emission factors is the AP42 produced by the US EPA[18], for fixed sources, and the COPERT, European system for the estimation of vehicle emission[19].

Finally, the economic valuation model has to take into account the monetary costs corresponding to each one of the valuated effects. These values can be obtained by means of the human capital method or the willingness to pay method. If the willingness to pay values are wanted to be obtained, there must be a consultation with professionals specialized regarding the valuation of intangible goods or hedonic goods. A wide range of professionals might be qualified to perform this sort of valuations. In Chile, the environmental economists as well as transportation engineers are the professionals with the best training on the subject. Transportation engineers in particular have a lot of experience in the subject after more than 25 years doing the valuation of intangible goods (among these travel times, possible accidents risks, noise, and advantages in terms of residential localization).

A government's pro-active role regarding pollution control requires promoting the training of professionals with the knowledge described above as well as an adequate investment in facilities and equipment. Moreover, this effort has to be sustained over time, attempting to encourage, whenever this is possible, the formation of expert professional networks of the different disciplines involved in the study of air quality.

1.4.1 Value Transfers

Many times there is no local evidence or only partial evidence is available. Even in these cases, it is possible to employ the damage function method, but using values transferred from other places. Every result transfer is at least subject to the original error, to which one must add the error product of the transfer. This last one will originate due to diverse factors, such as different geographical situations, different socioeconomic situations, or variations in the preferences both over time and in different zones at the same time.

The technique of goal analysis might help to improve the cohesiveness of the transferred values. This consists in considering a group of available studies, for example, on the willingness to pay

[18] The web page where this information is posted in detail is: http://www.epa.gov/ttn/chief/ap42/index.html

(WTP) for improvements in air quality. Each study is considered an observation and it consists in establishing an statistical relationship between the values obtained from the WTP (dependent variable) and certain variables representing the site in question (socioeconomic variables, geographical variables), which according to the judgment of the researcher have an impact on the study. Once the variables that have an influence on the observed differences in the individual valuations are determined, this additional information can be used to enhance the quality of the data obtained.

The value transfers alternative can be considered to be a valid short-term solution. However, when thinking in long-term, the convenience of performing studies becomes *crucial*. Many air quality-related phenomena have particular features. For example, the experience in United States and Europe suggests that in the majority of urban centers the formation of O_3 can be decreased with a reduction of VOC emissions primarily and NOx. Studies done in the Metropolitan Zone of Mexico ([Molina and Molina 2002], chapter 5) suggest, however, that it is actually convenient to reduce NOx emissions. Disregarding this fact, could lead to an excessive assignation of resources destined to reduce VOC emissions, without achieving the wanted results in the Metropolitan Zone of Mexico.

1.5 Cases of application of economic valuation of the air quality

In this section some examples of the use of benefit valuation in an air quality policy are shown in different contexts. The aim of this section is to illustrate the reach and usefulness of these valuation techniques before describing in greater detail the study cases that will be seen in the next chapter. First there is a description of the use of air quality valuation in social cost-benefit analysis in the European Union, USA and a few developing countries, and secondly various judicial criteria for damage valuations are depicted.

1.5.1 The E.U. case

In 1991 the European Commission began Project ExternE (http://externe.jrc.es). Its objective was to measure, in a detailed form, the external costs (or externalities) associated with the different fuel cycles. The adopted methodology for the project is based in a focus of the damage function and

[19] COPERT is an acronym for: “Computer Program to Calculate Emissions from Road Transport”, available from http://reports.eea.eu.int/Technical_report_No_50/en

considers the following impacts: human health and mortality, materials, agriculture, ecosystems, visibility and global warming. The research project "ExternE Core/Transport"[20] has prepared different studies to estimate the costs and benefits of transportation and technological measures using the Ecosense tool. This has been already applied in several European countries such as Germany, Belgium, Spain, Finland, France, Greece, and the United Kingdom.

For example, in Paris the potential for an emission reduction was analyzed by introducing electric vehicles. The study calculated the external costs associated with atmospheric pollution from electric vehicles, and conventional ones using gasoline or diesel. The study showed that the external costs of pollution associated with emissions from mobile sources are high, even for those cars that comply with the most recent and strict emission regulations. It was calculated that the non-internalized costs represent around 4% of the cost of a gasoline-fueled car and a 70% of diesel vehicles. If these costs were internalized, it is concluded that the prices of electric cars would be competitive against diesel vehicles but not against gasoline-fueled: for these it would be more cost-effective to introduce technological solutions instead of substituting these with electric cars.

1.5.2 The U.S.A. case

In the United States the project evaluation processes depends greatly of each State's policies, since it is a federal country. Only when federal funds are required, there should be proceedings regarding evaluation schemes for projects exemplified by the central government. In environmental terms, Section 812 of the Clean Air Act Amendments requires the Environment Protection Agency (USEPA) to periodically evaluate the effects of the Clean Air Act on public health, the economy and the environment. However, with means to establish environmental regulations, cost – benefit analysis is not utilized.

Up until now, the USEPA has prepared two cost and benefit analyses of the Clean Air Act, a retrospective one, for the 1970-1990 period [EPA 1997], and another prospective for the 1990 – 2010 period [EPA 1999]. Both studies are based in the damage function method, only using American-developed studies. Health benefits in particular are valuated using values based on the willingness to pay. Table 4 shows a summary of the cost-benefit analysis of the 1990-2010 Clean Air Act. This Act consists in the establishment of a series of measures destined to ameliorate the quality of air. Amongst the most important ones are the following:

[20] For a complete description of the Project and its components visit the website http://externe.jrc.es/transport_project

- Establishment of a detailed program for the execution and maintenance of the national air quality standards.
- Regulation of mobile sources and establishment of new requirements regarding gasoline for automobiles.
- Expansion and modification of the hazardous pollutant regulations: 189 pollutants considered highly toxic are categorized.
- Establishes a control program for acid rain precursors.
- Requires a new system of emission permits for primary emission sources.
- Limits the emission of chemical compounds that damage the atmospheric ozone layer.
- Introduces new measures to allow a tighter control from the authorities.

Table 4 Present Total Value of the 1990-2010 Clean Air Act (thousands of millions of US$ from 1990)

Direct costs	210
Direct benefits	1.200 (260 – 2.500)
Net benefits	1.000 (50- 2.300)
Rate: Cost / Benefit	6/1 (1/1 a 12/1)

The inferior and superior ranges correspond to the 5th and 95th percentiles (trust interval of 90%) Source: [EPA 1999]

For the authorities in charge of the Clean Air Act it was reassuring to know that, in the worst case scenario, the Act's benefits equal its costs. Taking the central value of the costs and benefits, the latter surpass the former six times, this way the evidence allows the assumption that all of the measures included in the Act bring an important benefit for US citizens. These benefits include health effects from the reduction of the concentration levels of PM_{10}, O_3, CO, NO_2 and SO_2, and other benefits due to improved visibility and effects on crops. Table 5 shows the distribution of benefits from pollution reduction according to its type: the majority comes from the reduction of effects on the population's health.

Table 5 Present value of benefits from the reduction of atmospheric pollution by the 1990-2010 CAA according to its type (US$ millions from 1990)

Monetary Benefits	Present Value
Mortality reduction	610.000
Morbidity reduction	50.000
Benefits on the environment and the well-being (includes visibility)	30.000
Stratospheric ozone reduction	530.000
Total benefits	1.200.000 (260.000 – 2.500.000)

Source: [EPA 1999]

1.5.3 Situation in Latin American countries

Only a few Latin-American countries explicitly include in their legislations a consideration of costs and social benefits for environmental plans or norms, and, as we will see ahead, even less have effectively performed this task.

In Chile, Law 19.300 of General Bases for the Environment establishes that in the elaboration of environmental quality norms and emission and decontamination plans, a stage of technical and economic analysis must be developed[21]. These criteria are developed in the Regulations on Norms for Environmental Quality and Emission, and in those which regulate the procedures for the dictation of the Prevention and Decontamination Plans, respectively. For Environmental Norms and Plans an estimation of costs and social and economic benefits must be considered. To carry out this task, it has been suggested the use of the methodology from Cost Benefit analysis as a conceptual scheme. The 1997 Prevention and Environmental Decontamination Plan in particular, [CONAMA R.M. 1997] employed Cost Benefit analysis methodology, using the damage function method; the 2001 update of the Plan also used the same methods [CONAMA R.M. 2001].

The Environmental Management Law of Ecuador also contemplates the requirement for every environmental norm dictated by the respective authorities to include an economic and technical analysis[22]. Therefore this must have been considered, for example, in the dictation of the fixed sources emission norms made in that country. In Peru, Supreme Order N° 074-2001-pcm, includes the National Standard Regulations and contemplates that in elaboration processes of action plans, there should be inclination to comply with the standards set forth and that "*cost-benefit analysis of the management strategies and instruments needed for its application*" must be considered.[23] In Mexico, the Third Program of Air Quality 2001-2010, created by the Metropolitan Environment [CAM 2002], presents as one of its elements, the economic valuation of benefits from an improvement of air quality and the impact that pollution reduction of PM_{10} and O_3 would have on human health and in the economic activity.

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[21] Regarding this point, read articles 32, 40 and 44 of Law 19.300 on Bases for the Environment.

[22] Article 4 of the Environmental Management Law points out, "The regulations, norms, orders, and controls that, inside the field of their competence the Government institutions issue regarding the Environment, must consider the following stages as considered pertinent; development of technical and economic studies for different sectors, studies on community relations and institutional capacities, consultation to competent institutions and to inform the civil sectors."

[23] Regarding this issue see article 16 of the National Standard Regulations for Environmetal Quality of Peru.

One can observe how in many Latin American countries, legislation expresses the needs to develop technical and economical studies in order to determine air pollution control norms. In others, although the legislation cannot be as restrictive in considering such an obligation, in fact, some of these studies are made in a public and unconcealed manner, such as in the Mexican case.

Part II Case Studies in Latin America

In this section three cases chosen from different metropolitan areas are presented: Santiago (Chile), Mexico City (Mexico) and Sao Pablo (Brazil). These cities have been chosen because they are the most advanced ones in Latin America regarding these issues, and because in all of them some sort of exercise of air quality valuation has been performed.

For Santiago de Chile the estimation of benefits is analyzed as part of the economic valuation of the 1997 Prevention and Economic Decontamination Plan (PEDP) of the Metropolitan Area and its 2001 update. Both plans underwent a thorough benefit-cost analysis by the National Commission of the Environment (CONAMA), based on studies made by external consultants, most of them Universities. These studies also contrast with the study previously prepared by the World Bank [The World Bank 1994].

In the Metropolitan Zone of the Valley of Mexico (MZVM) various studies are analyzed: the World Bank /RIVM study [Cesar, Dorland et al. 2000], studies made by the team led by Dr. Mario Molina [Molina and Molina 2002], and the recent co-benefits evaluation of the reduction of greenhouse gases [McKinley, Zuk et al. 2003]

For Sao Paulo we will analyze the evaluation of the Integrated Plan for Urban Transportation (IPUT) [da Costa, Saldiva et al. 1999] prepared for the World Bank, and the analysis of PROCONVE's impacts on the population's health [Braga, Pereira et al. 2002] and its monetary valuation [Ortiz and Serôa da Motta 2002] of the first part of the IES[24] project of the USEPA in Sao Paulo.

[24] For a description of the studies prepared during this program (initially known as ICAP), it is suggested to consult the Web page: http://www.nrel.gov/icap/

2. Case: Santiago de Chile

In the Chilean public sector there is an important tradition in the use of Analysis Cost Benefit methodology to determine the social profitability of public works. A clear example is the economic evaluation of urban transportation infrastructure projects: the Executive Secretary of Transportation Planning (SECTRA) has developed a series of computational tools that allow the estimation of social benefits from these projects; these basically consist in reducing traveling times. Beginning in 1994, this tradition of projects' social evaluation was extended to environmental plans, with the promulgation of the Law 19.300 of General Bases for the Environment.

This law establishes that in the elaboration of decontamination plans and norms environmental an estimation of the economic and social costs and benefits should be considered. The Regulation for the Dictation of Environmental Quality Norms and Emission (Supreme Decree Nº 93/1995) establishes that "the costs and benefits for directly affected or protected population, ecosystems or species; and the costs and benefits for the Government as responsible of inspecting the execution of this norm should be evaluated." This evaluation receives the name of General Analysis of the Economic and Social Impact.

Article 44 of Law 19.300 establishes that, by means of a supreme decree from the Office of the General Secretary of the Presidency, prevention and/or decontamination plans will be elaborated, the execution of which will be mandatory in zones categorized as latent or saturated. A zone is denominated to be latent when the measurements of pollutant concentrations in the air, water or soil ranges between an 80% and 100% of the value of the respective environmental quality norm; and to be saturated when one or more environmental quality norms are surpassed by the concentrations measured in the environment.

The regulation that adjusts the proceedings and stages for establishing prevention and decontamination plans (Supreme Decree nº 94/95 of the Office of the General Secretary of the Presidency) establishes that during the scientific studies stage that happens prior to the enactment of the draft bill, the Executive Director of the National Commission for the Environment (CONAMA in Spanish) must request, among other precedents, an estimation of the social and economic impact of the instruments used for environmental management and of the promotion for the improvement of the environment, that could be used. Then, once the scientific studies are completed, the

Executive Director must request a *General Analysis of Social and Economic Impact* (*GASEI* or AGIES in Spanish) for the plan, which must be evaluated within forty days.

Other instances in the legislation regarding aspects related to economic and social impacts of these instruments are:

The law and regulations do not specify which particular use will be given to the studies and precedent records of economic and social nature; this way the primary aim of the *GASEI* studies is to help in a more informed decision making process. In Chile and in the context of elaboration of an environmental plan or norm, it is possible to indicate at least four general uses for the studies and precedent records of economic and social nature, beginning with the ones described in the legislation (DII, 1997):

- As efficiency criteria in deciding the instruments to be implemented in a prevention or decontamination plan. For example, by giving priority in the initial valid stages of the plan, to those instruments that are assumed to have high efficiency in reducing emissions and implementation and operational costs;
- As criteria, among others, to define the goals of a prevention or decontamination plan;
- As efficiency criteria in the revision of environmental norms;
- As design of emission norms criteria, by means of an economic and technical feasibility analysis.

The precedents resulting from these studies are aimed, in first place, toward those responsible for the formulation of these instruments, but also, being a public document, to inform those who could be potentially affected by these regulations, of the impacts or effects that are expected to be generated in the environment where they subsist.

As summary, the actual Chilean environmental legislation demands the elaboration of economic and social impact studies in prevention and environmental decontamination plans and in the establishment of norms for pollutants' emission. The legislation does not determine which particular use must be given to these studies; therefore, it is implied that these constitute a tool in the search for more efficient solutions and in the diffusion of information to all of the community.

In the following section the proceedings for the economic valuation of the Prevention and Environmental Decontamination Plan (PEDP) for the Metropolitan Region of Santiago are shown.

2.1 Prevention and Environmental Decontamination Plan for the Metropolitan Region

In the year 1997, the first Prevention and Environmental Decontamination Plan (PEDP) was elaborated for the Metropolitan Region of Santiago de Chile, as this zone was declared saturated with four atmospheric pollutants (breathable particulate matter, total particulates in suspension, carbon monoxide, and ozone) and on August 1st 1996 as latent for nitrogen dioxide. This section and the following ones are based in the Prevention and Environmental Decontamination Plan of the Metropolitan Region, Santiago, Chile, prepared by the National Commission for the Environment of the Metropolitan Region. [CONAMA R.M. 1997]

The Plan consisted in identifying activities and sources of pollutants' emission and in elaborating reduction strategies of emissions for each group of activities with the means to comply with the air quality goals established for the year 2011[25]. The following five types of activities were identified:

Activities and sources associated with transportation

Strategy 1. Reduce emissions per vehicle.

Strategy 2. Define specific policies for the reduction of emissions associated with passengers and freight transportation.

Strategy 3. Incorporate the environmental variable in transportation planning.

Strategy 4. Avoid new motorized trips.

Activities and sources associated with industry, commerce and construction.

Strategy 1. Reduce emissions from already existing sources.

Strategy 2. Establish mechanisms of industrial growth sustainability for atmospheric emissions.

Strategy 3. Optimize the source inspection system

Strategy 4. Control the emissions originated from construction.

Activities and sources associated with agriculture

Strategy 1. Control the emissions originated from agriculture.

Domestic activities and sources.

Activities and sources associated with suspended dust.

Strategy 1. Territory planning in latent and saturated zones.

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[25] These goals correspond with the execution of the environmental norms for all pollutants. This raises an interesting problem, because when these norms are executed, the region will probably remain in a latent state, when a Prevention Plan should have been continued.

Strategy 2. Handling and conservation of soil resources.

The Plan has the year 2011 in its horizon and two stages are considered in this analysis period. The first of these covers the 1997-2005 period and the second stage, the 2005-2011 period. The plan is of dynamic nature and has to be reformulated in the years 2000 and 2005 to incorporate a better knowledge of the atmospheric pollution problem and the introduction of more efficient technologies. In the two following sections there is an economic valuation report prepared in the year 1997 and the updated version for the year 2000, finally prepared in 2001.

2.2 Prevention and Environmental Decontamination Plan Benefits. Year 1997

The most important direct benefits pertain to improvements in human health, especially the decrease of premature death risk. Other considerable direct benefits come from material damage reduction, increases in agricultural production, the decrease of critical episodes and an increase in visibility. Quantified results are delivered for the majority of the direct benefits, except for the reduction of critical episodes and increases in visibility.

The quantification of health, materials, and agricultural benefits associated with the implementation of the PEDP was prepared following these steps:

a) Two scenarios of environmental concentration were defined: a “base scenario”, without the PEDP, in which the concentrations in the environment increased according to population growth and the economic activity; and a “scenario with the PEDP” in which the environmental concentrations linearly decreases until reaching the primary norms in the year 2011[26]. Using these scenarios as a starting point, the differences in concentrations for the required pollutants were calculated in order to estimate the benefits.

b) The respective dose-response functions were applied to the differences in concentrations, which gave as a result the number of negative impacts evaded by the PEDP;

[26] Besides setting the goals according to the concentrations in the environment, lineal or roll-back models were used to estimate the required reduction in the emissions of environmental pollutants precursors. Unfortunately, neither background levels nor non-lineal representations were considered in these models, this is the reason why in the revision of the evidence for the 2000 update of the PEDP it was verified that the reductions estimated originally were insufficient, thus there was a demand for more challenging reductions. This was interpreted by some sectors as a change in the PEDP’s goals, when in reality this was not the case since the goals always consisted in the execution of the primary norms of environmental quality.

c) Regarding economic valuation techniques, a monetary value was assigned to the cases estimated in b), and later the present value of these was calculated

2.2.1 Improvements on human health benefits.

The quantification of the direct benefits associated with human health considers premature death risk reduction and a decrease in the incidence of different diseases and effects. To estimate the premature death risk increase, a time series study done in Santiago for the years 1989 to 1991 was used [Ostro, Sanchez et al. 1996] To valuate these reductions in death risk, the human capital method was used: the economic benefit associated to an statistical death increased to US$ 42,497. The benefits as a result of the diseases evaded by the PEDP were estimated for PM_{10} and ozone (O_3). The quantified benefits include the saved expenses on medical treatments and the incomes that were no longer being produced due to absences in the labor force. The present value [27] of the total of human health benefits produced in the 15 years of application of the PEDP amounts up to US$467 millions.

2.2.2 Benefits from material improvements

For the estimation of these benefits, the external surfaces of the infrastructure in the housing and commercial sectors of neighborhoods located in Santiago's suburban areas were considered. The rest of the sectors (industry, health, and others) were not included due to the fact that these constructions only represent a small fraction of the total, and because its construction materials are considered to have complex characteristics. This way, based on the data of the 1992 Census, the homes and offices surfaces were differentiated according to its predominant construction materials: plaster,-concrete and wood.

Taking into account the sedimentation effects (filthiness) produced by the total suspended particles (TSP), the repair expenses (wall painting) evaded by the PEDP were calculated. On the other hand, the costs for each repair were determined based on the market price of painting jobs and to the stock of surface exposed to pollution. This way, the total benefits present value from minor material damages was determined to reach US$ 445 millions.

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[27] For the present value calculation, a 12% discount rate was used, which was the social discount rate used in the evaluation of all the public investment projects in Chile, according to the Secretary of Planning recommendations. The rate decreased to 10% in the year 2001.

2.2.3 Benefits from increments in agricultural productivity.

Even though there is a consensus concluding that both ozone (O_3) as well as sulfuric oxides (SOx) have a negative influence in agricultural production, this analysis only considers the effects resulting from ozone. Regarding the analyzed zone, the estimation of these benefits only considered the Mapocho's river basin comprising the Santiago and Chacabuco provinces. In this geographical extension, the cultivated surface covers approximately 28,300 hectares, having as its primary crops fruits, vegetables, fodder, and other "traditional" crops. This way, considering both the quantified impacts as well as the studied zones, the increases in agricultural productivity can be interpreted as a conservative estimation of the benefits associated to fewer damages to the vegetation.

For those crops that included a dose-response function, the productivity losses evaded by the PEDP were calculated using the results average of the different functions. For those other crops where it was impossible to find dose-response functions, the evaded productivity losses were calculated based on the impact averages from those crops where the functions were known. The losses were valuated in market prices with the commercialization costs discount. This way, the benefits from the PEDP from fewer damages to the agriculture correspond with the income losses evaded by agricultural producers. The estimated benefits present value associated with agricultural production reaches up to US$ 144 millions.

2.2.4 Benefits Summary

Table 6 summarizes the benefits that were quantified in the PEDP analysis, indicating the form in which the different social actors, the population, the emitters, and the Government gained from them.

Table 6 Quantified benefits generated by the PEDP for the population, the emitters and the Government (millions of US$).

Benefit	Population	Emitters	Government	Total
Human health	392		75	467
Materials	445			445
Agriculture		144		144
Critical episodes		38	2.2	40
Quantified totals	837	181	77	1.095

Source: [CONAMA R.M. 1997] Table 9.15. Note: values may not correspond with the totals because these have been rounded off to two significant figures.

2.2.5 Implementation costs and profitability of the Prevention and Environmental Decontamination Plan

In order for these benefits to become a reality, it is necessary that the emission sources and the Government incur in important costs. In Table 7 the PEDP costs are detailed. According to the contents evaluated in this analysis, the present value of the costs required to execute the PEDP reaches up to at least US$ 911 millions out of which 48% are absorbed by the emitters and 52% by the Government. Besides, the PEDP points out significant non-quantified costs for the population. This way, identically to the case of the benefits, the total costs of the PEDP are higher than those quantified in this analysis. Keeping this in mind, the values presented in Table 7 must be interpreted as minimum total benefit and costs levels of the PEDP. Finally the Benefit/Cost ratio increases to 1.2.

Table 7 Quantified costs for the execution of the PEDP (US$)

	Emitters	Government	Totals
Transportation	300,261,383	163,984,218	464,245,601
Industry, commerce, and construction	51,435,857	26,071,250	77,507,107
Agriculture	268,824	1,121,003	1,389,827
Domestic	-52,253,008	0	-52,253,008
Re-suspended dust	0	119,617,550	119,617,550
Extrapolated costs	134,198,998	139,160,592	273,359,589
Subtotal	433,912,053	449,954,613	883,866,666
Environmental education	0	10,336,884	10,336,884
Follow up	0	17,027,161	17,027,161
Subtotal	0	27,364,045	27,364,045
TOTAL COSTS	433,912,053	477,318,658	911,230,711
TOTAL BENEFITS	181,337,029	77,052,610	1,095,615,780
Ratio Benefit/Cost	**<1**	**>1**	**1,20**

2.3 Re-estimation of the Benefits from the Prevention and Environmental Decontamination Plan. Year 2000

In the year 2000 a PEDP update was required as part of its normal process of evolution. This update considered all the new precedents obtained since the dictation of the original Plan until that date, especially the results of a hearing performed to the original Plan from a group of international experts [Lents, Larssen et al. 1999]. The update included a cost-benefit analysis of the most important measures included in the new Plan, which required a health benefits re-estimation. This re-estimation had three additional objectives to the estimation performed in 1997:

- To consider the growing evidence leading to think that fine particulate matter was much more aggressive for health than thicker fractions.
- To improve distinguishing amongst the primary pollutants that contributed to the formation of secondary particulate matter in the atmosphere.
- To identify both the sectors that received the benefits as well as the type of benefit.

The benefits associated with material damages and to the increases in agricultural productivity were not re-calculated. Benefits for improvements in visibility were also included, which had not been stated in monetary terms before. Ahead, we will briefly review how each of these benefits was estimated.

2.3.1 Human health benefits.[28]

This section is based on [Cifuentes 2000]. For these benefits calculation the function of the damage technique was used again; however, some modifications were introduced regarding to the calculations done in 1997.

If we only consider the benefits from mortality reduction for the 2000– 2005 period (the first stage of the Plan), these amount up to US$ 710.2 millions. Undoubtedly, the benefits notably increased by using a value based on the willingness to pay in order to valuate the benefits from mortality reduction.

2.3.2 Benefits from visibility improvements

To calculate these benefits, the results from the contingent valuation study prepared by Sánchez and Valdés [Sánchez and Valdes 1997] were used to estimate the willingness to pay by the inhabitants of Santiago for visibility improvements. The total benefits for improvements in visibility amount up to US$26.8 millions.

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[28] Also look over Appendix II.

2.3.3 Summary

Table 8 shows the benefits and costs of the PEDP for the period between 2000 and 2005, a period for which a total benefits and costs estimate was aptly calculated. The health benefits have been significantly increased, due to the fact that the willingness to pay method was used: these represent 91% of the total benefits. The rest of the benefits are from fewer damages from pollution in construction materials and from better visibility.

Table 8 Benefits and Costs PEDP 2000 – 2005 (millions of US$ from 2000)

Benefits	**Emitters**	**Government**	**Population**	**Total**
Industry, commerce, and housing	0	39	304	343
Fuel and transportation	0	44	344	388
Suspended dust	0	2	47	49
TOTAL BENEFITS	0	85	695	780
Cost	**Emitters**	**Government**	**Population**	**Total**
Industry, commerce, and housing	4	0	0	4
Fuel and transportation	103	0	0	103
Suspended dust	0	26	0	26
TOTAL COSTS	107	26	0	133
NET SOCIAL BENEFIT	-107	59	695	647
BENEFIT/COST				5,9

Source: [CONAMA R.M. 2001].
Note: all values rounded off to two significant figures. The costs and benefits present value was calculated using a discount rate of 12%. Fatal effects only consider short-term exposition.

2.4 Health benefits comparison from the PEDP according to the 1997 and 2000 valuation criteria

Finally, we present the health benefits of the original PEDP and the same benefits calculated according to the analysis methodology used in the update of the year 2000. This is done to illustrate and point out to some apparent detractors, the results sensitivity including the importance of the premature deaths reduction. Table 9 allows appreciating how the health benefits increase in more than 1000% with the new methodologies of the year 2000, in other words, the benefits increase in more than one magnitude order. This makes obvious the fact that different estimations used to perform an analysis may result in values that deeply differ.

Table 9 Health benefits comparison according to the evaluation criteria of the 1997 and 2000– 2005 PEDP (millions of dollars from 2000)

Effect	Analysis 1997			Analysis 2000			
	Government	Population	Total	State	Private Sector	Population	Total
Premature deaths	-	120	**120**	72	21	2.766	**2.859**
Chronic bronchitis	22	70	**92**	335	106	218	**659**
Minor restricted activity days	0,4	1,3	**1,7**	-	-	280	**280**
Job layoffs days	-	-	**-**	124	37	57	**217**
Respiratory symptoms	1,8	5,9	**7,8**	-	-	55	**55**
Hospital admissions	13	43	**56**	24	10	7,7	**42**
Asthma attacks	-	-	**-**	-	-	12	**12**
Hospital visits by infants Low IRA	8,1	26	**34**	6,2	3,2	2,4	**11,8**
Visits to the emergency room	4,1	13	**17**	5,6	2,8	1,2	**9,5**
Acute bronchitis	-	-	**-**	-	-	0,6	**0,6**
Restricted activity days	8,1	26	**34**	-	-	-	**-**
Days with asthma symptoms	3,2	10	**14**	-	-	-	**-**
Total Morbidity	60	196	**257**	494	160	633	**1.287**
Total	**60**	**317**	**377**	**566**	**181**	**3.399**	**4.146**

Source: [Cifuentes 2000] Notes: Mortality effects only consider short-term expositions.

3. Case: Mexico City

As mentioned before, several studies are analyzed for the Metropolitan Zone of the Valley of Mexico (MZVM): the study prepared by the World Bank/RIVM [Cesar, Dorland et al. 2000], the studies prepared by Dr. Mario Molina's team [Molina and Molina 2002], and the recent of the co-benefits evaluation from the greenhouse gases mitigation [McKinley, Zuk et al. 2003]. Following-up is a description of each one of them.

3.1 Study: Economic Valuation of Air Quality Improvement in the Metropolitan Zone of the Valley of Mexico

This study [Cesar, Dorland et al. 2000] was under the supervision of the Institute of Environmental Studies (IVM in Spanish), Vrije University Amsterdam, and the National Center of Environmental Health (CENSA in Spanish) and had for objective the economic valuation of the Third Program of Air Quality 2001-2010 (PROAIRE in Spanish). This program was elaborated by the Metropolitan Environmental Commission (CAM in Spanish) with means of protecting the population's health and reducing the number of environmental emergencies in the Metropolitan Zone of the Valley of Mexico (MZVM).

The study considers a reduction in the concentration levels of two environmental pollutants: ozone (O_3) and particulate matter (PM_{10}). To attain this reduction the Program proposes a series of measures destined to reduce the emission of the primary pollutants PM_{10}, nitrogen oxides (NO_x) and Volatile Organic Compounds (VOC)[29].

3.1.1 Considered Scenarios

The Third Program of Air Quality 2001-2010 considers four possible air quality improvement scenarios, which are listed below in a decreasing order of plausibility[30]:

i. Uniform 10% reduction of air pollution.

ii. Uniform 20% reduction of air pollution.

iii. Air pollution reduction until fulfilling the requirements of health protection norms in the entire metropolitan area (AQSI scenario).

iv. Air pollution reduction until fulfilling the requirements of health protection norms in the most polluted areas of the entire MZVM (68% and 47% reduction in ozone and PM_{10} concentrations, respectively) (AQS2 scenario).

The comparison point for these four scenarios are the concentration and emission levels of PM_{10}, SO_2, NO_x and VOC in the average values of the 1995 – 1999 period. In other words, it is assumed that with the actual air quality management conditions in the basin, there is not going to be a variation in air quality measurements. Although it is true that this comparison point is conservative, it must be considered that the four air quality improvement scenarios were not constructed starting with the application of an atmospheric model based in an emissions reduction scenario, but instead they were estimated beginning with the spatial interpolation of environmental concentrations of O_3 and PM_{10} available in the vast Automatic Network of Environmental Monitoring (RAMA in Spanish) of Mexico City. Considering the fact that important spatial gradients of ozone and PM_{10} are available today n the Mexico City basin, it is not completely obvious that the previous scenarios are technically feasible to achieve by emission reduction, especially the AQS1 and AQS2 scenarios, in particular for ozone, which presents important spatial gradients.

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[29] PM10 and NO_x are primary pollutants precursors of PM10 and the VOC, of O_3.

[30] Meaning that scenario i) is the most feasible and iv) the least feasible.

However, the strength of this study lies on the fact that the calculation of environmental exposition to pollutants has been done combining environmental and population concentrations data, to better categorize the population's exposition.

The decreases in environmental concentrations levels of O_3 and PM_{10} required for fulfilling each one of the four scenarios' goals can be appreciated in Table 10. It can be clearly noted that scenario i) is the one that has the higher success probability, because it requires the least amount of effort of emissions reduction for precedent pollutants.

Table 10 Estimated reduction in the concentrations measured on population to fulfill each one of the scenarios

Scenario	**Reduction in the measured population's exposition to ozone *(ppm)***	**Reduction in the measured population's exposition to PM_{10} *($\mu g/m^3$)***
10% exposition reduction	0.0114	6.41
20% exposition reduction	0.0227	12.81
SCA1 Fulfill the norm in the MZVM	0.0702	14.06
SCA2 Fulfill the norm for polluted areas	0.0778	29.99

Source: [Cesar, Dorland et al. 2000] Chart 4.1, Pg. 18

3.1.2 Health effects reduction

Starting with the reduction in population's exposition and environmental concentrations for each pollutant, the decrease in mortality and morbidity effects incidences was calculated. Concentration-response ratios were used in order to estimate these effects; the ratios were obtained from a locally developed goal-analysis, prepared based on international and Mexican studies, the latter using a double coefficient, in order to consider local conditions. The effects from premature mortality as a result of acute exposition and chronic exposition were considered as well. For this last one the studies developed by Pope and colleagues in the US, were used applied directly to Mexico City [Pope III, Thun et al. 1995].

The reduction in the number of health impacts generated in each one of the tour scenarios is presented in the following tables. Table 11 shows mortality reduction as a consequence of concentration level reductions of the chosen environmental pollutants. The adult mortality reduction is expressed as Lost Years of Life (Años de Vida Perdidos or ADVP in Spanish), meaning, the increase- expressed in years- of the life expectancy in the MZVM as consequence of air quality improvement. Infantile mortality, on the other hand, is expressed as number of cases.

Table 11 Deaths reductions or Lost Years of Life in the MZVM in 2010 for the four analyzed scenarios

Effect	Pollutant	Metrics	10%	20%	AQS1	AQS2
Mortality from acute exposition	Ozone	ADVP	5.457	10.913	33.740	37.367
Infant mortality	PM_{10}	Cases	266	533	585	1.247
Mortality from chronic exposition	PM_{10}	ADVP	14.131	28.261	31.016	66.143

Source: Cesar et al. (2000), Chart 5.4, Pg. 31.

Table 12 on the other hand, presents the mortality reduction, differentiated according to the different types of health impacts. All of these values are expressed as number of case reductions.

Finally, Table 13 presents the number of avoided environmental contingency days. During the environmental contingency days, the industry must reduce its levels of activity and, therefore, an opportunity cost is generated: the productivity loss. This effect is also valuated in the present study. Although this effect does not represent a social benefit associated with the effects of pollution (this value corresponds to the costs of stopping the industry due to environmental regulations), it has been included in this analysis because it is interesting to compare its magnitude with that of the health benefits. A section on the valuation methods that were used is included in Appendix III.

Table 12 Morbidity Cases Reduction in the MZVM in 2010 for the four analyzed scenarios

	O_3				PM10			
Effects	10%	20%	AQS1	AQS2	10%	20%	AQS1	AQS2
Hospital admissions								
- Respiratory	3.300	6.600	20.404	22.597	688	1.376	1.510	3.221
- Cerebral-Cardiovascular	842	1.684	5.207	5.767	291	582	638	1.361
Heart Strokes (in the old age)					0,36	0,71	0,78	1,66
Respiratory Emergency Room Visits	21.429	42.857	132.501	146.746	11.858	23.717	26.029	55.507
Restricted Activity Days (adults)	6.383.683	12.767.367	39.472.696	43.716.341	1.506.488	3.012.976	3.306.724	7.051.646
Lost labor days (adults)								
Total (infants)					2.106.747	4.213.495	4.624.287	9.861.371
Labor days lost by women because of infant's RAD								
Minor Restricted Activity Days	3.330	6.660	20.591	22.805				
Total (adults)					1.569	3.139	3.445	7.346
Effects on asthmatics					115	230	252	537
Cough without phlegm (infants)								
Cough with phlegm (infants)					3.063	6.126	6.723	14.337
Chronic Morbidity					574	1.148	1.260	2.686
Chronic Bronchitis, new cases	404	809	2.501	2.770				

Source: [Cesar, Dorland et al. 2000] Charts 5.2 and 5.3, Pg. 30.

Table 13 Reduction in the number of Environmental Contingencies for air quality improvement

	Base	*I (10%)*	*II (20%)*	*III (AQS1)*	*IV (AQS2)*
Days of EC for PM 10	1	0	0	0	0
Days of EC for ozone	10	2	0	0	0

Source: [Cesar, Dorland et al. 2000]Chart 6.10

3.1.3 Results

In this section we exhibit the economic valuation results from the Third Program of Air Quality. For this, Table 14 displays the results of the three different air quality improvement scenarios discussed above. The table also shows the results based on two different assumptions of how air quality varies depending on income. As presented in the column representing an elasticity of (0.4), less variable elasticity would mean that in a country with an inferior per capita income, environmental valuation would correspond to a larger portion of the income. Table 16 displays the benefits summary due to a reduction in PM_{10} and ozone in the MZVM.

Table 16 Benefits summary due to a reduction in PM_{10} and ozone in the MZVM (millions of US$ per year)

	Air Quality Scenario					
Valuation Scenarios	**10%**		**AQS1**		**AQS2**	
Transfer elasticity	**1**	**0.4**	**1**	**0.4**	**1**	**0.4**
Ozone benefits						
Total - Morbidity (Prod. loss+ COI +CVM) and - CVM based WTP for mortality	1.005	1.404	6.213	8.684	6.881	9.617
Total - Morbidity (Prod. loss+ COI +CVM) and - Human capital losses mortality	599	720	3.701	4.455	4.099	4.934
Total - Morbidity (Prod. loss + COI) and -Human capital losses mortality	493	493	3.046	3.046	3.374	3.374
Environmental contingencies benefits	36	36	45	45	45	45
PM_{10} benefits						
Total - Morbidity (Prod. loss+ COI +CVM) and - CVM based WTP for mortality	1.411	2.454	3.098	5.387	6.606	11.488
Total - Morbidity (Prod. loss+ COI +CVM) and - Human capital losses mortality	589	1.063	1.293	2.334	2.756	4.977
Total - Morbidity (Prod. loss + COI) and -Human capital losses mortality	158	158	346	346	737	737
Environmental contingencies	4	4	4	4	4	4

Source: Cesar et al. Chart 6.9, pg. 44

As it can be appreciated in the table, the results are sensitive to the transfer elasticity value used, but even more sensitive to the valuation assumptions used. For example, for the 10% reduction scenario, using an elasticity of 1.0 (first column of the table), it can be seen that the benefits associated with PM_{10} reductions can vary from almost 1.500 millions of dollars per year (if we consider the WTP to valuate the mortality and morbidity effects) to only 158 millions, if only the disease and lost productivity costs are considered. A large portion of the benefits comes from the WTP to reduce the death risks. This phenomenon occurs in all the analyzed studies.

3.2 Study: Air Quality in the Mega-City of Mexico

This study was developed by an experts group in environmental issues lead by Chemistry Nobel Prize winner Mario J. Molina [Molina and Molina 2002]. Experts in atmospheric sciences, human health, economy, political sciencies, and sociology contributed in this *Integral Study* on the air quality in the Metropolitan Area of Mexico City. Chapter 4 of this book illustrates the kind of social benefits, in monetary terms that a program aimed to improve air quality should have.

The secondary pollutants ozone (O_3) and breathable particulate matter (PM_{10}) were considered. The study performs an approximate estimation ("back of the envelope", as the authors themselves name it) of a sole scenario's benefits characterized by a 10% reduction in the concentration levels of both pollutants. These benefits include, in the case of O_3 only a reduction in the death numbers and chronic bronchitis cases and, regarding PM_{10}, only a reduction in the number of deaths and restricted activity days[31].

3.2.1 Results

The estimated annual benefits of a 10% reduction in the PM_{10} and O_3 levels in the Metropolitan Area of Mexico City are presented in Table 17..

Table 17 Social value of benefits from a 10% reduction in PM10 and O_3 levels in the Metropolitan Zone of the Valley of Mexico

Effects	Effect Reductions (cases / year)	Unitary values (US$ / case)	Social value (US$ Millions / year)
Mortality (PM10)	3,000	650,000	1,650
Chronic bronchitis (PM10)	10,000	34,000	340
Total benefits PM10			**2,000**
Mortality (O3)	300	650,000	200
Restricted activity days(O3)	2,000,000	6	10
Total benefits O3			**200**
Total Benefits			**2,200**

Source: Molina y Molina (2002), Tables 4.8 and 4.9

[31] See Appendix 4 for more details on the valuation method.

As it can be seen in the table, the benefits resulting from this approximate calculation have a similar magnitude to those obtained in the previous study, although the benefits from the reduction of PM_{10} are higher than the ones from ozone. The main difference is in ozone related mortality, and in the absence of morbidity benefits also associated with ozone, which can be important as shown in the previous study,

3.3 Local Benefits from Atmospheric Pollution Control in Mexico City

3.3.1 Objectives and evaluated policies

This study [McKinley, Zuk et al. 2003] was recently developed by the National Institute of Ecology and Mexico's National Institute of Public Health, and pertains to the second phase of the Integrated Environmental Strategies Program of the USEPA (Integrated Environmental Strategies, IES). The objective was to evaluate the local environmental benefits of a group including five measures regarding the control of greenhouse gases emission, which also produce reductions in local pollutant emissions. These measures include 1) A renovation of the taxi fleet, 2) extension of the Metro (subway) lines, 3) use of hybrid buses, 4) reduction of liquid gas losses, and 5) energy and heat co-generation.

3.3.2 Considered Pollutants

There is an estimation of the economic benefits from reducing the concentration levels of particulate matter (PM_{10}) and ozone (O_3). For this, the reductions in the emission of PM_{10}, sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_X) and hydrocarbons (HC) are estimated. Also considered, is an emission reduction of greenhouse gases: carbon dioxide (CO_2), methane (CH_4) y nitrous oxide (N_2O), which stimulated these measures in the first place.

3.3.3 Considered Scenarios

The five measures described above are considered as different projects. Each one of these projects has an impact on environmental pollutants concentrations. Table 18 displays the annual reduction expected in the emission of precedent pollutants of PM10 and O_3. Table 19 displays the changes in environmental concentrations of these that will be experienced by the population.

Table 18 Total annual reduction in the emission of primary pollutants

	Annual emission reduction (ton / year)							
Period	PM_{10}	SO_2	CO	NO_x	HC	CO_2	CH_4	N_2O
2003-2010	74	82	169.576	5.246	19.941	946.192	81	500
2003-2020	91	140	175.863	4.307	17.725	1.340.485	116	476

Source: Adapted from [McKinley, Zuk et al. 2003]Table II.1 Pg. 4. Total reduction for all the considered measures.

Table 19 Changes in the annual exposition to PM10 and in the maximum daily exposition to O_3.

PM10 annual average $\mu g/m^3$	Maximum daily O_3 $\mu g/m^3$
0,58	6,17
0,57	4,84

Source: adapted from [McKinley, Zuk et al. 2003], Table II.3, Pg. 6. Corresponds to the sum of the impact of all the measures.

3.3.4 Considered Effects

By using the concentration-response models taken from three previous studies (the study of the USEPA in the US in 1999, and the two Mexican studies previously analyzed (Cesar et al and Molina y Molina), the positive effects on the population's health that will generate the implementation of the measures under study were estimated, as it is shown in Table 20.

Table 20 Annual health impacts reduction (cases / years)

Impact	2003-2010	2003-2020
Acute mortality		
Total mortality	80	71
Infant Mortality	47	46
Chronic Mortality		
Total	9	10
Cardio-respiratory	1	0
Lung Cancer	10	10
Chronic Bronquitis	**728**	**713**
Hospital Admissions		
Respiratory	271	220
COPD	46	36
Cardiovascular	1	0
Heart stroke	1	0
Ischemic Desease	0	0
Pneumonia	60	47
Asthma	27	21
Emergency Room visits		
Respiratory causes	1314	1053
Asthma	1219	972
Restricted Activity Days	**21691**	**21563**
Minor Restricted Activity Days	**650.236**	**545.338**
School Absenteeism	**284.204**	**239.529**

Source: McKinley, Table II.4a and 4b, Pgs. 7 and 8

3.3.5 Valuation Methods

Once the impacts on the population's health were estimated, the benefit was quantified in monetary terms. For this, two valuation scenarios were used following the example from the Cesar et al study: the first one considers benefits from mortality and morbidity reduction according to the human capital method; the second one according to the willingness to pay method.

To valuate deaths reduction, the values shown in Table 21 are used. Regarding the rest of the values corresponding to health effects, the ones from the Cesar et al. (2000) study are used.

Table 21 Unitary values of effects (US$ per case)

Endpoint (Effects)	**COI**	**Productivity Loss[1]**	**WTP (Central estimate)**	**WTP IC 95%**
1.1 Acute Mortality				
Total mortality	-	9,005	506,000	81,120 – 2,600,000
Infant mortality	-	212,400		
1.2 Chronic Mortality				
Total	-	45,420		
Cardio-respiratory	-	45,420		
Lung Cancer	-	45,420		
1.3 Chronic Bronchitis	17,750[2]	80.9	30,000	4394 – 141,000
1.4 Hospital admissions				
All Respiratory	2,186	115.6	330	154 – 550
Asthma	603	23.1	330	154 – 550
COPD	17,750[3]	173.4	330	154 – 550
Pneumonia	2,111	92.5	330	154 – 550
All Cardiovascular	10,890	127.1	330	154 – 550
Congestive Heart Failure	13,300[3]	173.4	330	154 – 550
Ischemic Heart Disease	8,481[3]	80.9	330	154 – 550
1.5. Emergency room visits (ERVs)				
Respiratory Causes	269	57.8	170	79 – 284
Asthma	317	23.1	170	79 – 284
1.6. Restricted Activity Days	-	11.6[4]	20	0 – 28
1.7 Minor Restricted Activity Days	-	5.8[4]	20	0 – 28
1.8 School Absenteeism	-	11.6[4]	20	0 – 28

Source: [McKinley, Zuk et al. 2003] Table VI.5 pg.140. Notes:

[1] For Average daily salary
[2] COPD hospitalization
[3] Summation of ICU cost and Hospital Admissions Cost
[4] Assume that each case of Restricted Activity Days and School Absenteeism is 1 day, whereas MRAD is ½ day.

3.3.6 Results

Table 22 displays the annual monetary benefits associated with the implementation of the five measures considered for two temporal perspectives; one for the 2003 – 2010 period, the other for the 2003 – 2020 period (both values correspond to a high estimation scenario). Also indicated are the saved Quality Adjusted Life Years (QALY).

Table 22 Monetary benefits and QALYs saved per year

	Total Monetary benefits (2003 millions US$ / year)	Total QALYs saved per year
Total 2003-2010	225,53	4.611
Total 2003-2020	208,73	4.442

Source: McKinley, Table II.5 and II.6 Pg. 10

As it can be appreciated in the table, the monetary benefits are approximately one magnitude order smaller than the ones presented in the two previous studies. This is due, of course, to the fact that the reduction in environmental concentrations considered in this study is also approximately one tenth of the previous ones (for PM_{10} for example, 0.58 $\mu g/m^3$ are considered vs. the 6.41 $\mu g/m^3$ of the first scenario from Cesar et al). Even when this may seem like a very small amount, ł is necessary to take into account that this study is the only one of the three that considers environmental reductions associated with decreases in emissions from the application of specific measures, in this case, the five described above. This puts in evidence the difficulty of the decontamination job – when reductions associated with real measures are considered, the obtained values are relatively small compared with the illustrative values used in the other analysis.

4. Case: City of Sao Paulo, Brazil

Two studies have estimated the social impacts of pollution in Sao Paulo. The first one dealt with the estimation of health effects and the costs of urban pollution in the evaluation context of the Integrated Urban Transportation Project (PITU in Spanish) of the Metropolitan Region of Sao Paulo [da Costa, Saldiva et al. 1999]. The second one consisted of the post evaluation of benefits associated with the implementation of the third stage of the Program of Control of Atmospheric Pollution from Mobile Sources (PROCONVE in Spanish) in Sao Paulo IES [Braga, Pereira et al. 2002; Ortiz and Serôa da Motta 2002]. Both studies were prepared jointly by two research teams: one from Faculty of Medicine of the University of Sao Paulo, in charge of the estimation of the health effects, and one team of environmental economists from the IPEA of Rio de Janeiro, in charge of the valuation of these effects.

Because both studies apply the same techniques, only the most recent one will be described, since it incorporates more updated information, unavailable at the time of preparation of the first study.

4.1 The Economic Impact of PROCONVE on health effects from Atmospheric Pollution in Sao Paulo, Brazil: An results transfer exercise

4.1.1 Objectives and evaluated policies

This study was developed as part of the Integrated Environmental Strategies Program of the USEPA by a team from the Experimental Laboratory of Atmospheric Pollution of the Pathology Department of the Faculty of Medicine of the University of Sao Paulo, led by Dr. Alfesio Braga [Braga, Pereira et al. 2002] and by a team from the IPEA of Rio de Janeiro [Ortiz and Serôa da Motta 2002]. The study had as objective the estimation of the benefits from morbidity and mortality reductions generated from air quality improvement due to the implementation of the third stage of the Program of Control of Atmospheric Pollution from Mobile Sources (PROCONVE) in Sao Paulo, which began to be effective in the year 1997. This program consists in the establishment of maximum emission limits for different vehicle categories.

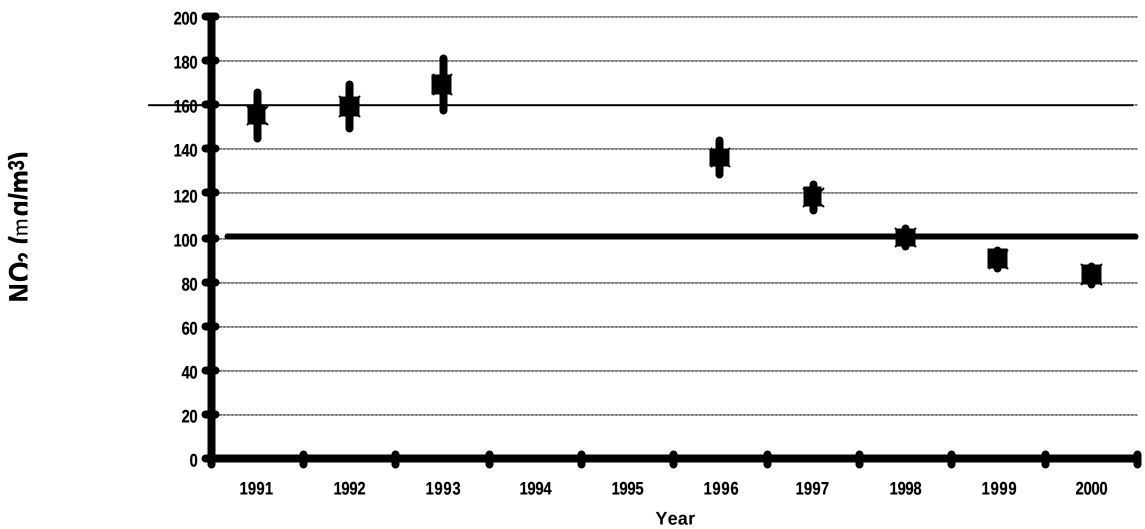
4.1.2 Considered Pollutants

The benefits from the reduction of the following pollutants were considered: nitrogen dioxide (NO_2), particulate matter (PM_{10}), sulfur dioxide (SO_2) and carbon monoxide (CO).

4.1.3 Considered Scenarios

Only one scenario was considered, defined by the reduction of the environmental concentrations observed as a result of the implementing the third stage of PROCONVE, during the 1997-2000 period. The following figure displays the annual average reductions of nitrogen dioxide concentrations, the pollutant that experienced the greatest reduction.

Figure 2 Annual NO_2 concentration averages in the metropolitan zone of Sao Paulo (annual standard = 100 μg/m^3)



Source: [Braga, Pereira et al. 2002] Figure 1.

4.1.4 Considered Effects

The effects reduction was estimated based on regression models developed in the same study, for the 1991-1994 period, and then applied to concentration reductions for the 1997-2000 period. The hospital admissions from respiratory causes were studied, as well as fetal mortality, and mortality in persons over 65 years old.

Table 23 presents the reduction of health effects generated in the 1997-2000 period due to the implementation of the third stage of PROCONVE.

Table 23 PROCONVE and its impact on health effect reductions in Sao Paulo

		Total Events		Events attributable to atmospheric pollution		Evaded events
		1991-1994	1997-2000	1991-1994	1997-2000	
Morbidity						
Respiratory admissions	0-2	99,581	80,232			
	PM10			10,756	6,712	4,044
	SO2			8,865	6,341	2,524
	CO			7,902	3,372	4,530
	>64	42,640	30,412			
	PM10			2,038	1,133	905
	SO2			1,184	752	432
Mortality						
	Fetal	12,565	11,250			
	NO2			2,945	1,525	1,420
	>64					
	Total	182,320	215,402			
	PM10			9,973	9,175	798
	SO2			11,513	12,091	-578
	CO			8,923	5,621	3,302
	Respiratory	26,603	31,110			
	PM10			2,642	2,395	247
	SO2			1,575	1,638	-63
Cardiovascular		88,019	99,581			
	SO2			3,301	3,324	-23
	CO			3,636	2,197	1,439

Source: [Braga, Pereira et al. 2002] Table 6.

It is necessary to note that SO_2 appears to be associated with an premature death increase. This is due to an increment in its average levels. However, the period's net effect is a reduction in the number of cases.

4.1.5 Valuation methods

The valuation was made based in value transfers. Table 22 shows the economic benefits for positive health effects from PROCONVE using a value from the WTP method**Error! Reference source not found.**[32]. Total economic benefits annual value was calculated to be approximately US$ 2,800 millions.

The table shows several points of interest. First, the core of the benefits is given by the willingness to pay to avoid premature mortality, primarily for those over 65 years old. The direct health

[32] Look over Appendix V.

expenses associated with hospital admissions correspond to a little over 18 million dollars, a small fraction of the total benefits.

Table 24 Monetary Values of Health Benefits– PROCONVE - Sao Paulo (Thousands of $US)

		Evaded Events		Health Benefits	
		0-2 years	> 64 years	0-2 years	> 64 years
Morbidity					
Respiratory				Transferred Costs	
Admissions	PM10	4,044	905	3,356	751
	SO2	2,524	432	2,094	358
	CO	4,530	--	3,759	--
	Totals	**11,098**	**1,337**	**9,209**	**1,109**
				Health Expenses	
	PM10	4,044	905	5,595	2,155
	SO2	2,524	432	3,492	1,029
	CO	4,530	--	6,267	--
	Totals	**11,098**	**1,337**	**15,353**	**3,184**
Mortality				Transferred Costs	
	NO2	1,420	--	819,686	--
	PM10	--	798	--	460,640
	SO2	--	-578	--	-333,647
	CO	--	3,302	--	1,906,057
	Totals	**1,420**	**3,522**	**819,686**	**2,033,051**
Total				**US$ 2,881 millions**	

Source: [Ortiz and Serôa da Motta 2002] Table 6

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Appendix

I.1 Appendix I. Economic valuation practices

I.1.1 Air quality benefits estimation

Why measuring the benefits associated with an improvement of air quality is such a complex task? As it will be explained below, this is due to the fact that there are no existing markets doing transactions with the concentration levels of pollutants in the air. If such markets existed, these would automatically become instruments of air quality management: these would indicate how much it costs to emit pollutants into the atmosphere, and those who would want to pollute should pay the price, otherwise they will not be allowed to do this. Figure 1 shows how a market of this type would work. In the horizontal axis, the measuring unit corresponds to the quantity of emissions (generally tons of pollutant) and in the vertical axis there is the cost per emission (generally dollars or *pesos* per tons of pollutant). The ascending curve is the marginal damages curve per emission units, in other words, if a certain amount of pollutants is emitted, the value corresponding to the vertical axis indicates the monetary costs for the society, of the last pollution unit[33],[34].The descending curve is the curve corresponding to the marginal savings: it displays the cost savings for emitters based on the last released pollution unit[35]. The point where both curves intersect determines the optimum emission levels. Up until that level, savings are superior to emission damages; therefore, pollution victims could be compensated by those who benefit with the emission of pollutants. On the contrary, if the emissions surpass level E*, the damage from the last pollution unit will surpass the savings.

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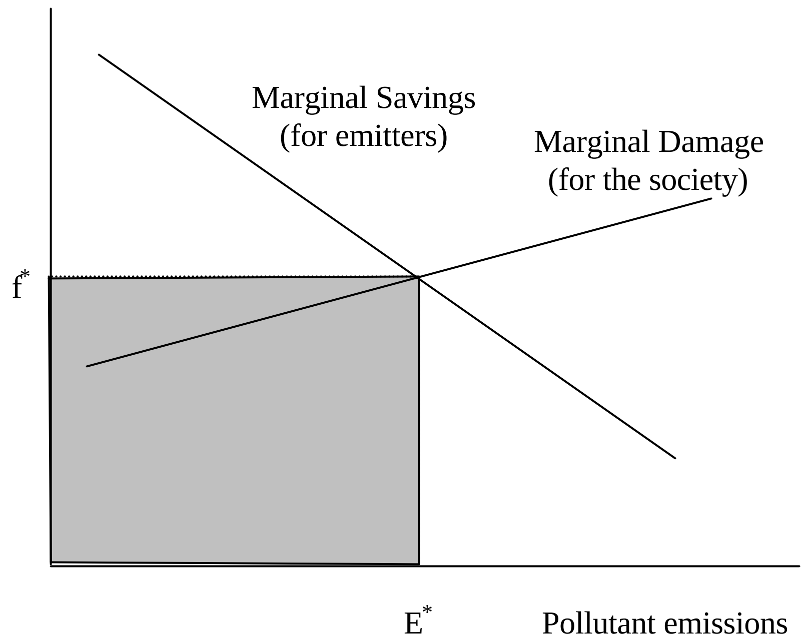
[33] As a matter of fact, the damage produced by pollution is a result of the pollutant concentration levels; this pollutant concentration is related to the emission of pollutants by means atmospheric dispersion. With the intention of simplifying this analysis, it is mentioned the damage caused by pollutant emissions, but the existence of the dispersion process must be taken into account: one pollutant emission level can generate different concentration levels depending of the geographical and meteorological conditions of the area.

[34] The total cost on the society is given by the area under the marginal damages curve.

[35] The total saving for the emitters is given by the area under the marginal savings curve.

Figure 3 Hypothetical Pollutant Emission Market



The optimum emissions amount corresponds to **E*; f*** is a fee paid by emitters**,** the total collected amounts up to **E*** x **f*** and compensates the caused damages.

Estimating the marginal damage curve for some types of damages is relatively easier[36]. For example, it is possible to determine how the pollution amount affects crops yield. In this particular case, the physical impact would be given by the amount of product no longer obtained, or by the difference in the quality of the cultivated product due to pollution effects. In both cases, these impacts can be immediately translated into monetary values: it only takes knowing the market price to calculate the economic loss[37].

In the majority of the cases though, the marginal damage curve is extremely complex to calculate. The most serious impact of atmospheric pollution on the population's health is the increase in

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[36] We emphasize relatively, because as the reader might assume, some steps involved in this estimation can be extremely complex.

[37] Assuming minimum impacts, meaning no significant effect is produced in the products market.

premature death risk. Quantifying this effect in monetary terms turns out to be complex because of two reasons. First of all, because it deals with the valuation of a very delicate issue such as the risks threatening people's lives, and second of all, because the scientific knowledge about this effects is not yet sufficient[38], and the mechanisms by which atmospheric pollution affects human health have not been completely explained at this point.

The two main categories of methods used to estimate the marginal damages curve in the following section are: direct methods and indirect methods. Before describing these, it is necessary the following clarification: valuating the marginal benefits from air quality improvement is exactly equal to valuating the marginal damages reduction. In other words, the benefit associated with an improvement in the air quality is equivalent to reducing the costs generated by poorer air quality.

I.1.1.1 Direct methods

Direct methods aim to obtain the people's willingness to pay for a better air quality in a direct way, by studying people's behavior. Two types of behavior can be observed: real or hypothetical. For real behavior is understood the actions effectively performed by the individuals, in which the air quality is economically valuated, in an implicit way. This is commonly known as *revealed preferences*. As a counterpart, there are *stated preferences*, based in the people's behavior when dealing with hypothetical market situations, presented in the form of surveys or experiments especially designed for this purpose.

By excellence, the revealed preferences technique for air quality valuation is the *hedonic prices technique* [Freeman III 1993; Azqueta Oyarzun 1994]. This consists in establishing a mathematical relationship between the price (or leasing cost) of a home and its attributes, among which environmental quality is included. Based on this information, it is determined the influence that each one of the attributes has upon the price of the home. Particularly the effect on air quality can be isolated, and this way, it can be determined how much people are willing to pay for living in a neighborhood with better air quality. The primary advantage of this technique lies on the fact that the real behavior of people is observed. However, this results in a disadvantage from a statistical

[38] However, in the last years, this knowledge has increased considerably, as a result of great research effort from the international community. Holgate, S. T., J. M. Samet, H. S. Koren and R. L. Maynard, Eds. (1999). Air Pollution and Health. San Diego, Academic Press.

standpoint, due to possible confusing biases: the -data quality is generally poor which can lead to non-cohesive results, especially if these are required as a support for decision making.

Another important disadvantage of this method is that it has a series of implicit assumptions, which are hardly met. The primary assumption refers to the existence of an ideal competitive real state market, which assumes that the individuals have total mobility across the urban area. It is very unlikely that this will happen in Latin-American cities, where great socio-spatial segregation usually exists: under these circumstances the decision of choosing a locality for residence is associated with social-status variables which may bias any effect that air quality may have.

One of the biggest objections to the use of direct methods for the valuation of air quality considers how fully individuals perceive pollution's harmful effects. Perceiving the visibility effects or material damages can be done in a more precise way, but the perception of health effects, especially long-term ones can be biased. Considering the fact that scientific knowledge regarding this matter is still insufficient, the more the reason to sustain the idea that regular people cannot express in a precise way their willingness to pay for a better air quality in order to prevent health damages, especially those that will occur in a very distant future from the moment they express their willingness to pay.

The *contingent valuation method* is one example of methods using declared preferences techniques. In a survey of contingent valuation, people are asked directly[39] about their willingness to pay for a better air quality. In order for the answers to be valid in this kind of survey, the concept of air quality must be defined in an accessible way so that the survey participants can really understand the good that is being valuated.

In both the direct methods described above, hedonic prices and contingent valuation, determining what people are actually valuating still needs to be defined: benefits from reduced health effects, benefits from better visibility, from fewer damages to materials or vegetation, or a combination of all of these. And regarding health benefits, it should be established which benefits are being considered: benefits from premature death reduction, benefits from the reduction of morbidity events, etc. This is one of the primary limitations of this method: many times it is impossible to

[39] There are many ways to formulate this questions, besides the direct question, which has many limitations. The one used the most today is to present the individual with a hypothetical transaction, in which they only need to express if they would or would not pay a certain amount for an improvement of air quality.

determine exactly what were the pollution impacts considered by the individuals at the time of expressing their willingness to pay.

I.1.1.2 Indirect methods

Indirect methods consist in using models to determine the physical impacts of pollution, and employing economic models to valuate these impacts. For one part, epidemiological or physical models are used to determine the effect that a change in the pollutant concentration has on the population's health, the visibility, and material and vegetation damages. Once each one of these impacts has been quantified, it is proceeded to translate them into monetary values using monetary valuation techniques. In the case of material damages or effects on crops, market prices may be used; in the case of health and visibility effects, for which there is no market, some of the methods described in section I.1.1. may be used.

The use of indirect methods is chosen today in the majority of studies that have estimated the benefits from atmospheric pollution reduction. The sequence of models receives the name of *damage function method*, and it is described in greater detail in the following section.

I.1.2 The damage function method

The last model of the sequence is the economic valuation model, which allows putting in monetary terms the changes on health effects. There are two methods for deriving these values. The *human capital* is the method traditionally used.

This method claims that the value associated with reducing a premature death or a morbidity episode is given by the income that is no longer generated as a consequence of this health effect. In the case of death it is the actual value of the total income that an individual no longer generates from the moment of their death until the moment in which they would have retired from the labor force. In the case of a morbidity episode, the human capital value is the loss of income generated by the health effect.

One alternative method, which is being increasingly used, is the *willingness to pay method or WTP*: it considers the maximum amount of money that people are willing to pay for reducing the death risk or the probability of suffering an event affecting their health. This way, reducing the premature death risk is not valuated by that which is no longer produced, but by the value that individuals assign to a reduction in the probability of their death.

This method of calculating the monetary value of the damage caused by pollution is very effective hypothetically, but difficult to apply in practical cases. The data from the few markets in which death risks are indirectly transacted can be used as well as hypothetical market methods.

Again, direct methods of revealed or stated preferences may be used. The hedonic prices method delivers a compensation estimate required from accepting death risks, by means of studying the relation between the salary of different occupations and its characteristics, one of which is the death risk of the occupation. This method is similar to the hedonic prices one, thus suffering from the same limitations, besides from a very significant additional limitation: it assumes that there is mobility in the job market, thus individuals voluntarily choose the occupation and the risk level. This way an adverse selection phenomenon is caused: those individuals less adverse to risk will choose the riskier occupations, thus the application of the study's results on the general population would be a sub-estimation. This is especially relevant, given the fact that one of the most important characteristics of risk acknowledgment, therefore of the required compensation, is the voluntary nature of risk exposition [Slovic 2000].

As counterpart, economists recur to pseudo or hypothetical market techniques in which the attempt is to infer the price that people would pay for a reduced death risk. These techniques will be implemented by means of the use of surveys.

The willingness to pay method may also be used to determine the amount of money that the population is willing to pay for better visibility.

I.2 Appendix II. Benefits on human health of the Prevention and Environmental Decontamination Plan of Santiago, Chile.

This section is based on [Cifuentes 2000]. To calculate these benefits, the damage function technique was again used; however, some modifications were introduced regarding the calculations done in 1997. First of all, only the fine fraction of particulate matter $MP_{2.5}$ was considered instead of the breathable particulate matter MP_{10}. Secondly, the health benefits were estimated using the willingness to pay value instead of the human capital method. The first of these changes was due to the increase in scientific evidence gathered in the last years of the 90s which indicates that the most harmful health effects are those produced by $MP_{2.5}$; the second of these changes was a result of the tested theoretical superiority that the willingness to pay method has over the human capital which in turn has resulted in an increased usage of it in the social evaluation of projects in many developed countries.

For the benefits calculation from reduced premature death, a new time series study was used in Santiago, which covered a more extensive time period, besides also considering $PM_{2.5}$ and ozone [Cifuentes, Vega et al. 2000]. Additionally, the group study prepared by Pope and colleagues in the US was used [Pope III, Thun et al. 1995] to consider it in a high benefit scenario. For the valuation of these effects, the values obtained by the USEPA in its Clean Air Act analysis [EPA 1999] were used, transferred to Chile using the per capita income relation, as well as the results of a contingent valuation study performed in Santiago [Cifuentes, Prieto et al. 2000]. The used value was US$650,000, about 14 times superior to the value used in 1997 which was based on human capital.

I.3 Appendix III. Valuation methods used in the MZVM case, Mexico

Three estimations of health benefits for each one of the four defined air quality scenarios were elaborated. In estimation 1, the benefits from avoided diseases were estimated according to the Willingness to Pay method (WTP), the Disease Costs (DC) and the productivity loss according to the Human Capital method (HC). To valuate the premature mortality reductions the WTP was considered. This estimation uses an income elasticity of 1.0 for benefit transfers.

For estimation 2, the same method was considered to valuate the disease reduction and the valuation for avoiding premature mortality was done via income (loss of HC). An income elasticity of 1.0 is again used for benefit transfers. The third estimation valuated the disease reduction according to the DC method and the loss of HC, and the mortality reduction using the HC method.

Table 25 summarizes in a concise manner the proceedings for each one of the estimations. It must be noted that the use of the willingness to pay method produces higher estimations of both the avoided premature death values and the reduced morbidity episodes. This way, the first method will produce the higher benefits, the second one an intermediate result, and the last one, the most conservative benefits value.

Table 26 Definition of Health Benefits estimation scenarios

	Health benefits components	
Scenario	Morbidity	Mortality
High	Productivity Loss + DC +WTP	WTP
Medium	Productivity Loss + DC +WTP	Loss of human capital
Low	Productivity Loss + DC	Loss of human capital

Source: Adapted from [Cesar, Dorland et al. 2000] Chart 6.1.
Note: all the value transfers are done with an income elasticity equal to 1.

Regarding the value of the WTP, the values estimated in the US are transferred by way of a standard type adjustment in the literature:

$$WTP_{(MEXICO)} = WTP_{(USA} \times [Income_{(MEXICO)} / Income_{(USA)}]^{IE}$$

where IE represents the income elasticity of the WTP in the US. The $WTP_{(MEXICO)}$ value is very sensitive both to the measure used for income (national gross product per capita, national gross product per capita adjusted according to the acquisition power, national average income) and to the adopted IE value. The smaller the latter, the higher the transferred $WTP_{(MEXICO)}$ value will be. An IE value equal to 1 (one) is considered a reasonable assumption for not producing extremely high

$WTP_{(MEXICO)}$ values. Regarding the income, this was adjusted by acquisition power, which causes the quotient value in the previous equation to increase.

Finally, it was necessary to assign a value to the Lost Years of Life (LYL), to obtain the Year of Life Value (YLV). Table 27 indicates how these values were obtained.

Table 28 Year of Life Value (YLV) in US$, from 2010 valuated with 1999 prices, 3% discount rate) a

Income Elasticity	*YLV Mortality from acute exposition*		*YLV mortality from chronic exposition*	
	Male	*Female*	*Male*	*Female*
0	184,750	179,776	140,611	138,308
0.4	131,961	128,409	100,434	98,789
1.0	79,660	77,515	60,628	59,635

a. A standard life value (SLV) of 4.28, 3.06, and 1.85 millions of US$ (from 2010 valuated using 1999 prices) were used after the benefits transfer from the European estimations of SLV of 3.36 millions of US$ (from 1999 valuated using 1999 prices) with an income elasticity of 0, 0.4 and 1, respectively.

b. The differences between males and females originate from different distributions of the probability of surviving and life expectancy.

Source: [Cesar, Dorland et al. 2000] Chart 6.5.

I.4 Appendix IV. Valuation method for the air quality study in Mega-Mexico City.

The valuation method used to measure the benefits is the willingness to pay and it is calculated by transferring the corresponding values from USA the following way:

$WTP_{(MEXICO)} = WTP_{(USA)} \times [Income_{(MEXICO)} / Income_{(USA)}]$,

where Per capita income $_{(MEXICO)}$ = US$3,970; $Income_{(USA)}$ = US$29,340; all the values expressed in dollars from 1990. In the case of mortality reduction benefits, it is used a $WTP_{(USA)}$ value equal to US$4.8 millions (value used by the USEPA in its 1990 analysis), a value of the WTP $_{(MEXICO)}$ equal to US$650,000 is obtained. Applying this formula for the chronic bronchitis case and restricted activity days, a willingness to pay US$34,000 and US$6 respectively are obtained.

I.5 Appendix V. Valuation methods of PROCONVE, Sao Paulo, Brazil.

The valuation was done based in value transfer. To valuate in monetary terms the health benefits, the willingness to pay method was used, transferring values estimated in USA using the following equation proposed by [Heintz and Tol 1996]:

$$DAP_{[Brasil]} = DAP_{[EE.UU.]} \left(\frac{Ingreso_{[Brasil]}}{Ingreso_{[EE.UU.]}} \right) \cdot \frac{E_{[Brasil]}}{E_{[EE.UU.]}} \cdot \frac{G_{[Brasil]}}{G_{[EE.UU.]}}$$

where the income (Ingreso) is given by the per capita income adjusted by the acquisition power, E represents life expectancy and G the national health expenses. The income elasticity of the WTP is assumed to be equal to one. This study is the only out of all the analyzed ones that uses this method for value transfer. Table 29 displays the transferred values using the traditional method (Factor 1) and the proposed method (Factor 2). As it can be appreciated, the values obtained with the traditional method are 2.26 times greater.

Table 30 WTP values transferred to Brazil (thousands of US$)

Effect	Factor 1	Factor 2
Life Statistical Value	1,306	577
Chronic Bronchitis	70.7	31.2
Cardiac Hospital Admissions	2,6	1,1
Respiratory Hospital Admissions	1,9	0,83

Source: [Ortiz and Serôa da Motta 2002] Table 3, values transferred starting with the central estimations of the USEPA. Original values based in [Davis, Krupnick et al. 2000] and [Hunt 2002].

Table 31 presents the monetary benefits from positive health effects of PROCONVE using the WTP transfer values. The annualized value of the total monetary benefits is approximately US$2,800 millions.

The table displays several interesting aspects. First, the core of the benefits is given by the willingness to pay to avoid premature death, especially of those over 65 years old. The direct health expenses associated with hospital admissions equal a little over 18 million dollars, a small fraction of the total benefits.

Table 32 Monetary values from health benefits – PROCONVE - Sao Paulo (thousands of US$ from 1999)

		Avoided events		Health Benefits	
		0-2 years old	> 64 years old	0-2 years old	> 64 years old
Morbidity					
Respiratory				Transfer Prices	
Admissions	PM10	4,044	905	3,356	751
	SO2	2,524	432	2,094	358
	CO	4,530	--	3,759	--
	Totals	**11,098**	**1,337**	**9,209**	**1,109**
				Health Expenses	
	PM10	4,044	905	5,595	2,155
	SO2	2,524	432	3,492	1,029
	CO	4,530	--	6,267	--
	Totals	**11,098**	**1,337**	**15,353**	**3,184**
Mortality				Transferred Prices	
	NO2	1,420	--	819,686	--
	PM10	--	798	--	460,640
	SO2	--	-578	--	-333,647
	CO	--	3,302	--	1,906,057
	Totals	**1,420**	**3,522**	**819,686**	**2,033,051**
Total				**US$ 2,881 millions**	

Source: [Ortiz and Serôa da Motta 2002] Table 6