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Valuation of the air quality regulation ecosystem service: impacts from a Brazilian Northeast industrial complex

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Abstract: This article analyzes the economic impact of industrial complex NO2 and PM10 (particulate matter) emissions on the ecosystem service (ES) of pollutant dilution in the atmosphere. To this end, the Pecém Industrial and Port Complex (CIPP), Brazil, was adopted as a case study. The ES economic valuation is based on increased healthcare costs associated with a higher occurrence of rhinitis and atopic eczema in adolescent children, derived from CIPP activities. The potential symptomatic population was calculated taking advantage of its relationship with the concentration of NO2 and PM10 pollutants. The monetization of the impact is carried out using the replacement cost method, comparing two scenarios: status quo and low emissions. The activities developed at the CIPP are found to result in an increase of US$ 720 thousand per year in health costs for the region. These costs represent a 70% increase in costs related to the diseases under analysis

***Keywords*:** Environmental economic valuation; air quality; atmospheric pollution; health costs; replacement cost method; industrial complex..

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1. FRAMEWORK

1.1 Air quality as an ecosystem service

The degradation of air quality by the emission of air pollutants leads to negative impacts on population health. The industrial and energy sectors oftentimes emit particulate matter and toxic gases, such as nitrogen oxides and sulfur dioxide, affecting nearby communities. With the change in atmospheric composition caused by these pollutants, there is an increase in the population's respiratory and allergic diseases. High concentrations of NO_2 are associated with the local development of asthma and rhinitis (WANG et al., 2020, NICOLUSSI et al., 2014). PM_{10} and NO_2 are associated with decreased respiratory functions in children (CASTRO et al., 2009, NICOLUSSI et al., 2014). Moreover, 70% to 85% of people with rhinitis symptoms are sensitive to aeroallergens, so they are predisposed to develop diseases such as atopic eczema (NICOLUSSI et al., 2014).

These social impacts resulting from anthropic interventions on the environment indicate a decrease (or weakening) in the supply of ecosystem services. As a result, there is a reduction in human well-being, especially for the most vulnerable population (MA, 2003; GÓMEZ-BAGGETHUN et al., 2009). With the study of ecosystem services, it is possible to identify society's dependence on environmental systems. A variety of approaches can be taken when attributing value to environmental components, among which the economic valuation of ecosystem services has been dominating (KALLIS et al., 2013). One of its main advantages is the possibility of comparing not only with other environmental aspects but also with other value spheres, such as economic and social. In addition, monetary valuation allows for incorporating socio-environmental externalities of economic activities into assessing their impacts (HANSON et al., 2012; BOIRAL, 2003).

There are criticisms pointed at the methodology due to the consequences of attributing the market logic to natural and common goods. This argument was made by Gómes-Baggethun et al. (2009) in his historical review of the development of the concept of ecosystem services and economic valuation. Its mainstreaming can promote the commodification of the environment. Even with the intention of conservation, it can shift the motivation of ethical obligation and sense of community towards individual and private economic interests. However, Kallis et al. (2013) defend its application when it enables 1) environmental improvements and 2) reduction of inequalities, 3) when it does not suppress other valuation paradigms, and 4) does not favor the centralization of goods. In these circumstances, economic valuation can be a helpful tool, even more so if integrated with economic and social policies. This is the case for the valuation of ecosystem services impacted by pollutants, enabling their quantitative assessment and establishing a basis for compensatory measures (KALLIS et al., 2013).

1.2 CIPP in Ceara, Brazil

One such cases where the valuation of ecosystem services can be put to the service of society is the assessment of the ecosystem service depletion and its economic impact on health costs by the Pecém Industrial and Port Complex (CIPP, for its name in Portuguese – Complexo Industrial e Portuário de Pecém).

The CIPP started its operations in 2001. It is located in the state of Ceará, Brazil, between the municipalities of Caucaia and São Gonçalo do Amarante, and is about 60 km of the state capital, Fortaleza. The CIPP covers an area of more than 13 ha and is divided in 4 main sectors: the first is intended for thermoelectric power plants and a steel mill; the second, for refinery and the petrochemical complex; the third, for the industrial area; and the fourth, for the services area. In total, there are 30 companies in the CIPP, generating more than 50 thousand jobs, directly and indirectly (AECIPP, 2022). The complex connects the state internationally, with focus on industrial activity. After the installation of the CIPP, both the municipalities of Caucaia and São Gonçalo do Amarante registered strong growth in the share of Ceará's GDP, especially São Gonçalo do Amarante, which had a 50-fold increase in GDP, compared to 2002 (CAVALCANTE et al., 2022).

Regarding the municipalities where the CIPP is located, Caucaia has a population of 325,000 people, and São Gonçalo do Amarante, 44,000 people. In both cities, populations are decentralized, distributed around industries. In Caucaia, 43% of the population has an average per capita income of less than 1/2 minimum wage [2019], while in São Gonçalo do Amarante this figure is 49% (IBGE, 2021a; IBGE, 2021b).

The climate in the region is mild tropical hot semi-arid (IPECE, 2017a; IPECE, 2017b). Moreover, the region is part of the Intertropical Convergence Zone (ITCZ), where the trade winds of the northern and southern hemispheres converge. As a result, the rainfall and wind regimes of the municipalities are strongly affected by this dynamic. In the second half of the year, the maximum intensities of the trade winds over the state occur, which is when the ITCZ migrates to its northernmost position of its climatological normal (CAMELO et al., 2008). Regarding topography, there is a prevalence of relief of coastal plain (IPECE, 2017a; IPECE, 2017b).

1.3 CIPP and air quality

Nuto et al. (2018, a) evaluated the occurrence of respiratory and allergic diseases in school children residing in the areas of direct influence of the CIPP. It was found that the diseases rhinitis and atopic eczema have a higher statistically significant occurrence in the CIPP region compared to the Brazilian average. The complex's foremost contributors to the emission of atmospheric pollutants are a steel plant, coal-fired thermoelectric plants, and a cement factory. The NO_2 and PM_{10} pollutants are concentrated in point emissions and fugitive emissions of particulate matter. Point-source stationary emissions are inherent to the production process, and mobile- and fugitive-source emissions arise from the transport and storage of coal and iron ore, as well as from vehicles (CEARÁ,

2009). These emissions affect the region's ecosystem services' capacity, thus assessing this reduction is a relevant environmental management instrument.

1.4 Relevant case studies

Air pollution may cause chronic diseases and related pathologies. Abe and Miraglia (2016) evaluated the effect of air pollution scenarios on respiratory and cardiovascular morbidity and mortality, as well as the associated health costs. They suggested that lower levels of particulate matter (PM10 and PM2.5) and ozone may save lives and substantial amounts of money, as well as reducing the demand for hospital care and improving medical assistance.

Chiquetto et al. (2016) showed that different air pollution limits correspond to different scenarios of impacts on public health cost planning. These scenarios can be worse with the exposure of vulnerable groups. For instance, local wind system of the sea breeze may carry air pollution to low-income areas.

Ratifying the importance of identifying health costs caused by pollution, Rivas et al. (2018) identified that vehicle emissions of NO_2 generate a cost of USD 112 thousand (base 2019) annually for pedestrians in the city of Pamplona, Spain. This assertion was made based on the prevalence of bronchitis in children aged 5-14 years. Previously, Karimzadegan et al. (2008) had already correlated additional health costs: USD 19 thousand (base 2019) for the increase of one unit of PM_{10} concentration; and USD 2,200 (base 2019) for the increase of one unit of NO_2 concentration in Tehran, Iran. Moreover, reducing pollution has also been seen to lead to lower health costs. Castro et al. (2017) reported that the reduction of 3.3 $\mu g/m^3$ in particulate matter emissions could generate savings of USD 540 thousand (base 2019) in the health system in the Lausanne-Morges region, Switzerland. Reinforcing these observations, Akhtar et al. (2017) estimated that 92.5% of Pakistan's population is willing to pay an average of USD 10 (base 2019) per month to improve air quality. This figure represents approximately 1.3% of the country's gross domestic product (GDP) per capita.

1.5 Scope

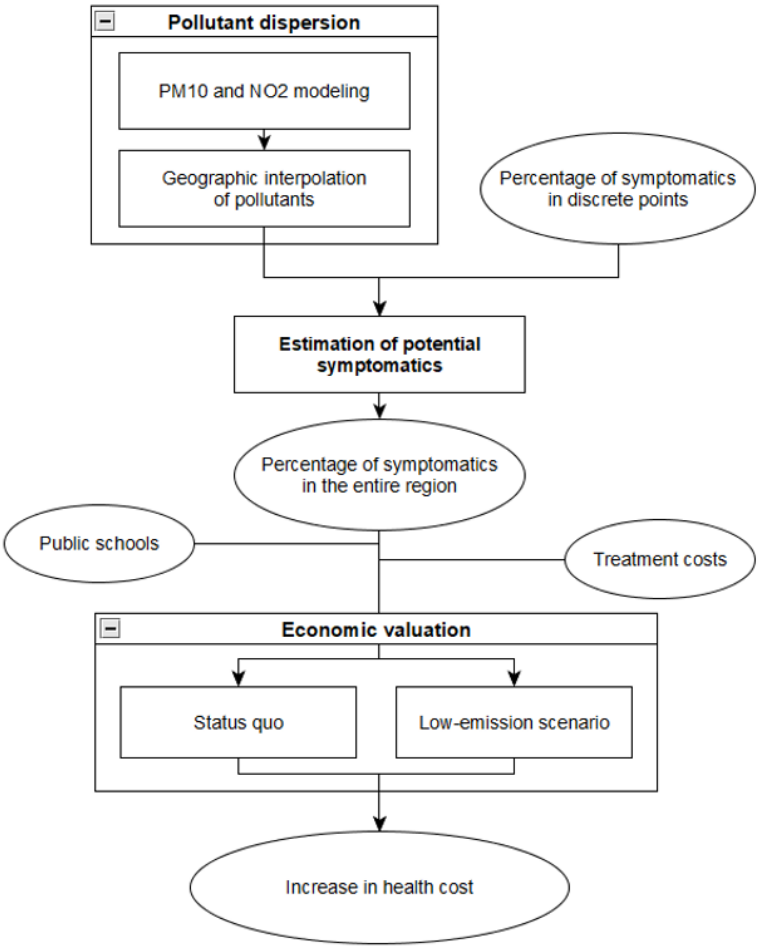
Within this frame, this paper investigates the impact of the CIPP on the ecosystem service of air quality regulation, exploring its relationship with local public health, and presenting an estimate of the monetary valuation of these impacts. The diseases selected to quantify the health cost are rhinitis and atopic eczema, as they present a significant statistical increase concerning the Brazilian average. Such diseases are related to atmospheric pollutants NO_2 and PM_{10}, emitted by the complex.

2. METHODOLOGY

The methodology proposed and employed in this work associates the high emission of atmospheric pollutants with the impact on children and adolescents' health. The capacity reduction of the ecosystem service in charge of diluting pollutants in the atmosphere and the subsequent local worsening of air quality is the central aspect to be considered. The economic valuation of the polluting activities' impact is based on the costs of restoring welfare to the affected population.

The flowchart (Figure 1) illustrates the adopted methodological roadmap, showing the three main steps of the valuation: "Pollutant dispersion", "Calculation of potential symptomatics" and "Economic valuation". These are respectively presented in sections 2.1, 2.2, and 2.3. The flowchart also shows the various inputs and results of the analysis marked with an ellipse.

Figure 1 - Methodological flowchart



Source: The authors.

2.1 Pollutant dispersion

In order to establish an association between air pollution and the occurrence of diseases, one must first study the pollutant dispersion patterns. This amounts to obtaining a map of the pollutant concentration. Such a map can be obtained in one of two ways: performing measurements at discrete points or numerically modeling the propagation of pollutants ejected from the various emitting sources. The first guarantees greater fidelity, while the second allows for the isolation of the effect of the emitting sources under study.

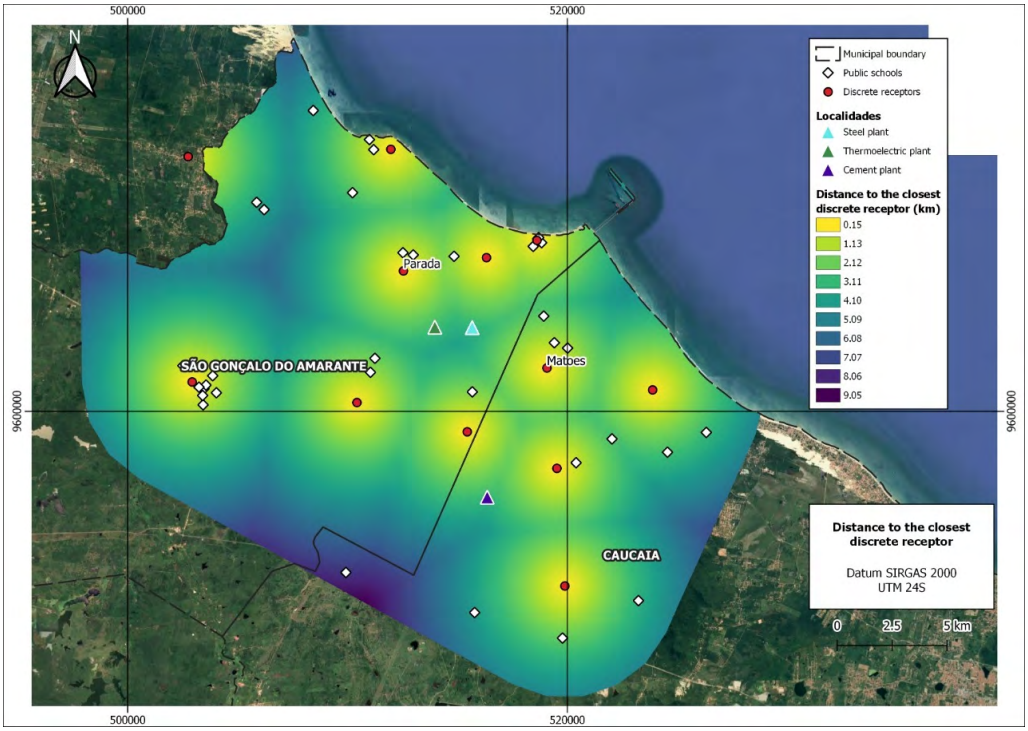
This work employed the latter since the goal is to study the isolated effect of the CIPP. The modeling (CEARÁ, 2009) was carried out based on the wind dynamics and the atmospheric emissions of the different elements of the CIPP: a steel plant, coal-fired thermoelectric plants, and a cement factory.

The wind dynamics in CEARÁ (2009) was obtained through hourly meteorological modelled data, for a period of three years (2005 to 2008). To this end, the MM5 prognostic numerical model (mesoscale model 5), developed by the Pennsylvania State University/National Center for Atmospheric Research (PSU /NCAR) was adopted. The MM5 results were further validated with real data, collected in the Taiba neighborhood of São Gonçalo do Amarante. The results were verified to be reliable, and adequately reproduce the wind field of the CIPP region.

For the CIPP emissions, the sources considered are point-source stationary emissions from chimneys and boilers, and mobile- and fugitive-source emissions arising from the transport and storage of coal and iron ore, as well as from vehicles. The study (CEARÁ, 2009) provided discrete receptors in the CIPP's aerial area of influence, selected for being critical points, and their respective maximum concentrations of NO_2 (1h) and PM_{10} (24h).

With the pollutant concentrations at the discrete receptors, the concentration map was elaborated geographically, interpolating NO_2 and PM_{10}. This was done using the Distance Inverse Weighting (IDW) interpolation method, implemented in a GIS software. A 5 km buffer was adopted around the polygon formed by the discrete receptors. This allows one to cover the maximum study area while maintaining the same interpolation accuracy present inside the polygon. Thus, the distances from the study points (public schools) to the discrete receptors are similar in the buffer area and the area inside the polygon (Figure 2), not exceeding 4 km. Except for the point in the figure's dark blue/purple area, which is excluded from the study. The interpolation area is also contained within the administrative limits of the municipalities of São Gonçalo do Amarante and Caucaia.

Figure 2 - Interpolation distance to the closest discrete receptor, together with the public schools located in the study area



Source: The authors.

In Figure 2, the red dots represent the discrete receptors provided in the pollutant-dispersion study (CEARÁ, 2009). Similarly, the white dots correspond to public schools offering education to children and adolescents aged 6 to 14.

Moreover, as the present analysis investigates two pollutants, a non-dimensional equivalent pollutant, accounting for both NO_2 and PM_{10}, is employed. To that end, the pollutant concentrations were normalized (Equation 1) by the air-quality guidelines for NO_2 (1h) and PM_{10} (24h) defined by the World Health Organization (WHO, 2006) and by the final standards of the Brazilian National Environment Council - CONAMA (Brazilian Ministry of the Environment - MMA, 2018). The normalization was performed considering these organizations' guidelines, which are still not achieved in most regions in Brazil. This departure of the normalization criterion from the Brazilian reality does not constitute a problem since the purpose of the normalization is to equate the harm on human health of different pollutants. WHO and CONAMA guidelines are thus an appropriate normalization denominator. These guidelines correspond to 200 $\mu g/m^3$ for NO_2 and 50 $\mu g/m^3$ for PM_{10}.

$$P = \frac{[NO_2]}{200} + \frac{[PM_{10}]}{50} \quad (1)$$

Where:

P = Non-dimensional equivalent pollutant.

$[NO_2]$ = NO_2 concentration $\mu g/m^3$.

$[PM_{10}]$ = Concentration of PM_{10} $\mu g/m^3$.

2.2 Estimation of potential symptomatics

In order to carry out an estimation of the symptomatic population, a law of equivalence between the presence of air pollutants and the occurrence of diseases is necessary. Such relations encompass complex biochemical processes that depend on many factors, making obtaining an analytical law extremely difficult.

In this work, a bisaturated linear relation based on discrete data points is adopted. Thus, this relation provides an association between the presence of NO_2 and PM_{10} pollutants (unified into the non-dimensional equivalent pollutant defined in Eq. 1) and the percentage of symptomatic individuals. The relation is based on the discrete points corresponding to the districts of Parada (in São Gonçalo do Amarante) and Matões (in Caucaia). The use of a linear law is justified by the positive and linear correlation between the levels of NO_2 or PM_{10} and rhinitis, reported by Nicolussi et al. (2014).

The mentioned discrete points were obtained from Nuto et al. (2018), who quantified the percentage of children and adolescents aged 6 to 13 years with symptoms of rhinitis and atopic eczema in the CIPP region in the municipalities of São Gonçalo do Amarante and Caucaia. The region displayed a symptomatic ensemble of 32% for rhinitis and 12% for eczema. These values are higher than those found for Brazil by the International Study of Asthma and Allergies in Childhood (ISAAC): 25.7% to 29.6% for rhinitis and 8.9% to 11.5% for atopic eczema. Moreover, the values are slightly higher than those found for the Northeast region, which vary from 26.1% to 32.4% for rhinitis and 9.9% to 11.2% for atopic eczema (SOLÉ et al., 2006).

However, if the neighborhoods are analyzed separately, Parada has 36% of children and adolescents with rhinitis symptoms and 14% with symptoms of atopic eczema. These values are much higher than the national and northeastern averages. On the contrary, the symptomatic populations in Matões are 24% and 7%, respectively.

Matões and Parada are located 9 km apart, with the CIPP elements located equidistantly between them. The difference in the occurrence of diseases between the two districts is hypothesized to be due to the air quality difference, consequence of the region's wind dynamics. The winds, predominantly from the East and Southeast, direct the pollutants from the CIPP to Parada, and away from Matões. In other words, Parada is in the pollutants' dispersion path. This ultimately leads to Parada having maximum

concentrations of 89.4 μg/m³ for NO_2 and 8.4 μg/m³ for PM_{10}, while Matões presents 24.7 μg/m³ for NO_2 and 0.4 μg/m³ for PM_{10} (CEARÁ, 2009?). Furthermore, Parada has the population reporting the highest worsening in their quality of life after the construction of the complex (NUTO et al., 2018, b).

Using these two discrete points, the potential percentage of symptomatic children and adolescents with rhinitis and atopic eczema (%S) per school unit was calculated by linear regression (Equation 2).

$$\%S_{School} = \frac{\%S_{Parada} - \%S_{Matões}}{(P_{Parada} - P_{Matões})} \times (P_{School} - P_{Matões}) + \%S_{Matões} \quad (2)$$

Where:

% S = percentage of children and adolescents symptomatic of rhinitis and atopic eczema.

P = Non-dimensional equivalent pollutant.

The linear regression is saturated by introducing both upper and lower bounds to it. These bounds are fixed at where . This amounts to ±6% for rhinitis and ±3.5% for atopic eczema. In other words, the minimum and maximum saturation values for rhinitis are 18% and 42%, respectively, while for atopic eczema, they are 3.5% and 17.5%.

Finally, the total population of symptomatic schoolchildren was obtained using the number of students aged 6-13 regularly enrolled in the region's public schools (Eq. 3). The student populations in each school correspond to values from the 2018 School Census. These are georeferenced by pairing with coordinates obtained from SPOT-5 GPS satellite images and cartographic bases (IPECE, 2019). In total, 35 public schools were identified in the study area, following the classification of section 2.1. The public schools host a total of 8226 children aged 6-13.

$$ES_{Total} = \sum \%S_{School} \times E_{School} \quad (3)$$

Where:

ES = Number of symptomatic students.

%S = percentage of symptomatic children and adolescents.

E = Registered population per school unit.

2.3 Economic valuation

In order to assign economic value to the impact on the ecosystem service of air quality regulation, the monetization is carried out using the Replacement Cost Method (RCM). In this method, the valuation of the benefits generated by an environmental

resource is calculated by the expenses necessary to replace or repair the damage caused to it (GARROD; WILLIS, 2002). The RCM is usually classified as a production-function method. It is based on substitutive markets due to the absence of actual market values for the ecosystem service itself. As an alternative to this method, one may quantify using shadow prices.

The great advantage of this method is the possibility of estimating the cost of restoring the health damage caused. Therefore, this cost becomes a measure to compensate society. This amount could be used to attempt to repair the impact so that the good reaches its original form. On the other hand, the value of the ecosystem service tends to be overestimated in this method. Since there are not many ways to estimate the replacement cost, often the most straightforward and most direct yet more expensive is employed (DEFRIES; PAGIOLA, 2005). Also, the validity of the results obtained depends on critically analyzing the inclusion of other costs and factors involved in replacing an environmental asset (TOLMASQUIM et al., 2000).

For the case under consideration in this work, the high emission of atmospheric pollutants by the activities of the CIPP reduces the efficiency of the ecosystem service for diluting pollutants in the atmosphere, worsening local air quality. This high concentration of pollutants causes diseases such as rhinitis and eczema, which increase the cost of health care for children and adolescents in the region.

Therefore, rhinitis and eczema treatment costs were applied to the population of symptomatic students in the municipalities of São Gonçalo do Amarante and Caucaia in the study area (Eq. 4). The cost of treating rhinitis is USD 62 per patient per year (COSTA et al., 2018) and the cost of treating atopic eczema is USD 1520 per patient per year (MESQUITA et al. 2019).

$$CD_{Total} = CD \times E \tag{4}$$

Where:

CD_{Total} = Total cost of the disease (USD .year-1);

CD = Cost of the disease (USD .person^{-1}.year^{-1});

ES = Number of symptomatic students.

The impact value is estimated by comparing two scenarios: status quo and a hypothetical scenario. In the latter, the air quality is assumed to have little or no influence from the complex. In this hypothetical scenario, it is considered that all locations within the area of interest present air quality similar to Matões - one of the discrete points mentioned in section 2.2. That is, the entire area of study presents a non-dimensional equivalent pollutant value equal to that of Matões. Despite being close to the CIPP, the wind dynamics do not allow pollutants carried by atmospheric dispersion to reach high levels in the locality, so Matões has one of the region's best air qualities.

3. RESULTS AND DISCUSSION

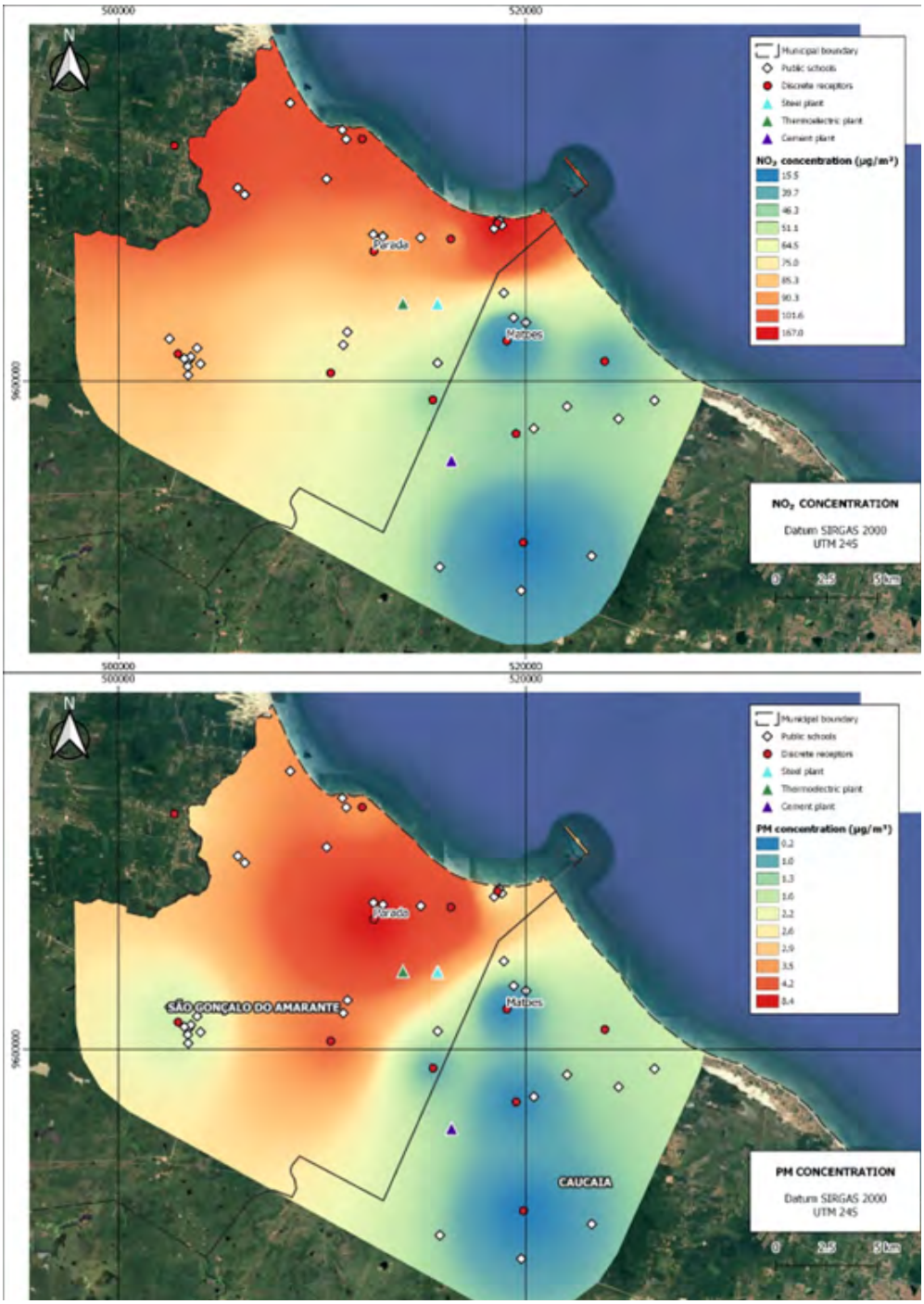
3.1 Pollutant concentration maps for NO_2 and PM_{10}

Higher pollutant concentrations were identified in the regions west and northwest of the CIPP (Figure 3). As a result, there is a higher occurrence of pollutants in the municipality of São Gonçalo do Amarante, located in the pollutant dispersion path, compared to that of Caucaia. Furthermore, NO_2 and PM_{10} have different dispersion patterns due to molecular weight and to difference in their physical state. The NO_2 has lower molecular weight and is in a gas state. On the other hand, the PM_{10} has higher molecular weight and is composed of both liquid and solid particles. For these reasons, NO_2 is dragged by the wind for greater distances, leading to high concentrations far from the emission point. The PM_{10} dispersion is such that the region of high concentration remains near the emission points, leading to higher concentration gradients.

The correlation pointed out by Nicolussi et al. (2014) between the concentration of PM_{10} and NO_2 and the presence of rhinitis and atopic eczema is verified since Parada, the district located on the pollutant dispersion path, presents a number of cases of rhinitis and atopic eczema higher than the district of Matões.

In Figure 3, the red dots represent the discrete receptors resulting from the pollutants' modeling. The white dots represent public schools with students aged 6-13, and the triangles indicate the position of the steel plant, thermoelectric plants, and cement factory.

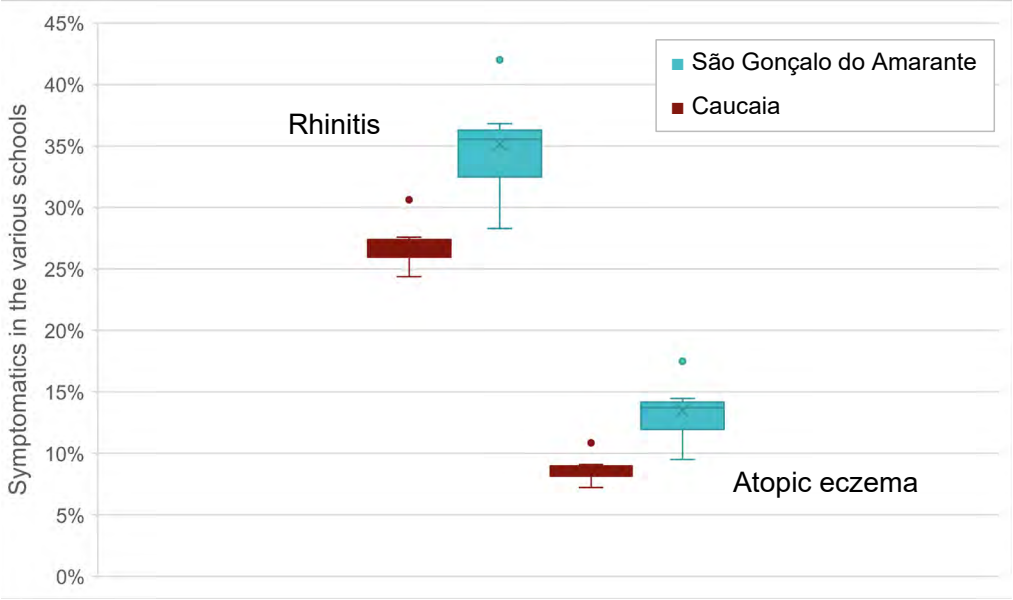
Figure 3 - Potential NO2 (top) and PM (bottom) concentration in the CIPP region of impact



Source: The authors.

3.2 Symptomatic children and adolescents

Figure 4 displays the estimated population of children and adolescents with symptoms of rhinitis and atopic eczema for each school under consideration. The percentage of symptomatics in the region of the municipality of São Gonçalo do Amarante is seen to be higher than that in Caucaia. The weighted average of rhinitis symptomatic patients in São Gonçalo do Amarante is 35.09% (with a standard deviation of $\sigma = 1.64\%$) while in Caucaia it is 26.78% ($\sigma = 3.87\%$). For atopic eczema, the values are 13.47% ($\sigma = 2.26\%$) and 8.62% ($\sigma = 0.96\%$), respectively.



Source: The authors.

In comparison to the discrete points, 6 schools present a higher estimated occurrence of the diseases than the global value indicated for Parada (36% for rhinitis and 14% for atopic eczema). Still, there are no schools with a lower occurrence of diseases than the global value indicated for Matões (24% for rhinitis and 7% for atopic eczema).

3.3 Increase in health costs

The annual investment required for the status quo scenario is USD 1,717 thousand to treat both rhinitis and atopic eczema. In the hypothetical low-emissions scenario, in which the influence of the CIPP is reduced, the annual cost of these diseases would be USD 997 thousand. Therefore, the budget increase of more than 70% represents the additional expenses necessary to deal with the rise in symptomatics attributed to the CIPP's industrial activities (Table 1). The additional health expenses, around USD 720

thousand (2019), can be thus considered as the monetary valuation of the impact on the ecosystem service of diluting pollutants in the atmosphere, and therefore on population health. The potential impact on the CIPP's area of influence represents 1.16% of the total health budget for both municipalities São Gonçalo do Amarante and Caucaia.

Table 1 – Symptomatic population and healthcare cost (USD/year) for the status quo scenario and the low-CIPP influence scenario

	Status quo		Low-emission scenario	
	Rhinitis	Atopic eczema	*Rhinitis*	Atopic eczema
Estimated symptomatic population	2,734	1,019	1,974	576
Healthcare costs	$169,272	$1,548,294	$122,234	$874,924
Increase in health costs	$47,038	$673,370	-	-
Total increase in costs	$720,407		-	

Source: The authors.

The study by Akhtar et al. (2017) points out that the willingness to pay for air quality improvement is 1.3% of the per capita income. For the population under study, the ensemble value corresponding to the children and adolescents would be USD7.5 million, based on the GDP of São Gonçalo do Amarante and Caucaia (IBGE 2021a; IBGE 2021b). This value corresponds to almost 300% of the identified impact in health costs. This suggests that the value people attribute to air quality encompasses more than simply the increase in health costs needed to treat diseases resulting from polluted air. In other words, people are also ready to pay to avoid the discomfort and loss in quality of life that comes with disease.

4. CONCLUSIONS

This article adopts the economic valuation as a methodological approach to assess the impact on air quality by a multimodal industrial complex. The research is based on secondary dataset applied to the case of the Pecém Industrial and Port Complex (CIPP), in the state of Ceará, Brazil. The economic impact of the complex's activities on the air quality was estimated by relating the concentration of NO_2 and PM_{10} derived from its emissions to the populations of children with rhinitis and atopic eczema. To that end, two scenarios were defined: status quo and a low-emission scenario.

An area of direct influence of the CIPP was defined around the complex, partially comprising the municipalities of São Gonçalo do Amarante and Caucaia. Within this area, regions with different pollutant concentrations were identified following the local wind dynamics. The pollutant-dispersion study shows that NO_2 and PM_{10} propagate differently in the atmosphere due to their different molecular weight. This confirms the need for specific studies for each pollutant.

The fractions of symptomatic children were estimated from the pollutant concentrations using a bisaturated linear relation. This relation is based on the data available on the occurrence of rhinitis and atopic eczema in children in the Matões and Parada districts.

The increase in the health cost necessary to treat rhinitis and eczema in children and adolescents (6-13 years of age) was estimated using the Replacement Cost Method. Due to the emissions resulting from the CIPP's industrial activities, the region of interest's health cost has an estimated increase of USD 720 thousand per year. Therefore, this value quantifies, in monetary terms, the impact of the CIPP on the air quality around it. In order to place it in context, the value represents 1.16% of the total health budget of both municipalities (São Gonçalo do Amarante and Caucaia), which have an ensemble population of over 400 thousand people. Moreover, it also amounts to a 70% increase in the health costs associated with the diseases under analysis.

This value in absolute terms should be considered with reservations since it is calculated using simplifications and hypotheses. Still, the quantification of the impact was potentially undervalued, given that the result is significantly less than the expected willingness of the population to pay for the improvement of air quality – USD 2 million (base 2019). It is noteworthy that the valuation would be considerably higher if it considered the population in other age groups besides children and adolescents. It is also important to note that the valuation presented considers only the cost of treating diseases, not giving value to people's loss of well-being. However, the result provides an order of magnitude, or rather a minimum quota, of the monetary value representative of the reduction in the local population's quality of life resulting from the complex's operation.

This work, therefore, highlighted the importance of valuing the impact of industrial activities on ecosystem services. Decision-makers can subsequently structure plans and actions in order to attempt to reduce the negative externalities caused on the ecosystem services capacity. The policymakers should prioritize areas most impacted for environmental and public health management, especially those inhabited by vulnerable population. The internalization of this social impact will ultimately lead to higher socio-environmental justice in the region.

Declaration of interests

The authors report no conflict of interest.

References

ABE, K. C.; MIRAGLIA, S. G. **Health Impact Assessment of Air Pollution in São Paulo, Brazil.** International Journal of Environmental Research Public Health, v. 13, 2016. https://dx.doi.org/10.3390%2Fijerph13070694AECIPP – Associação das Empresas do Complexo Industrial e Portuário do Pecém. **A nova ordem industrial e logística do Ceará**. Available at: http://www.aecipp.com.br/pt-br/cipp. Accessed on: March 1st of 2022.

AKHTAR, S., SALEEM, W., NADEEM, V.M., SHAHID, I., IKRAM, A. **Assessment of willingness to pay for improved air quality using contingent valuation method**. Glob. J. Environ. Sci. Manag. 3, 279-286. 2017. DOI: 10.22034/gjesm.2017.03.03.005.

BOIRAL O. **Sustainability reports as simulacra? A counter-account of A and A+ GRI reports**. Accounting, Auditing and Accountability Journal, Vol. 26 pp. 1036 – 1071, 2013.

CAMELO, H. N., CARVALHO, P. C.M., LEAL JUNIOR, J. B. V., ACCIOLY FILHO, J. B. P. **Análise estatística da velocidade de vento do estado do Ceará.** Rev. Tecnol. Fortaleza, v. 29, n. 2, p.211-223, dez. 2008**.**

CAUCAIA (GOVERNO). **Ofício de encaminhamento da prestação de contas do governo prefeitura municipal de Caucaia**. Disponível em: <http://www.sefincaucaia.com.br/downloads/balancogeral/balanco_geral_2019.pdf>. Acesso em: 01 de fevereiro de 2021.

CASTRO, A., KÜNZLI, N., GÖTSCHI, T. **Health benefits of a reduction of PM_{10} and NO2 exposure after implementing a clean air plan in the Agglomeration Lausanne-Morges**. Int. J. Hyg. Environ. Health 220, 829–839. 2017. DOI: 10.1016/j.ijheh.2017.03.012.

CASTRO, H. A., CUNHA, M. F., MENDONÇA, G. A. S., JUNGER, W. L., CUNHA-CRUZ, J., LEON, A. P. **Efeitos da poluição do ar na função respiratória de escolares**, Rio de Janeiro, RJ. Revista de Saúde Pública, 43(1), p. 26-34. 2009. DOI: 10.1590/S0034-89102009000100004

CAVALCANTE, A. L., MEDEIROS, C. N., PAIVA, W. L. **Impactos Socioeconômicos do Complexo Industrial e Portuário do Pecém (CIPP)**. IPECE Informe – Nº 204 – January/2022.

CEARÁ (Assembleia Legislativa). **Cenário atual do complexo industrial e portuário do Pecém / Conselho de Altos Estudos e Assuntos Estratégicos**. Assembleia Legislativa do Estado do Ceará, Eudoro Walter de Santana (Coordenador). – Fortaleza: INESP, 2013.

CEARÁ (Secretária de infraestrutura). **Complexo Industrial do Pecém – CIP - Estudo de Dispersão Atmosférica**. Silvio de Oliveira (Coordenador). – Fortaleza: ENTEC, 2009.

CHIQUETTO, J.B.; SILVA, M.E.S.; CABRAL-MIRANDA, W.; RIBEIRO, F.N.D.; IBARRA-ESPINOSA, S.A. et al. **Air quality standards and extreme ozone events in the São Paulo megacity**. Sustainability, v. 11, n. 13, p. 3725, 2019.

COSTA, E., CAETANO, R., WERNECK, G.L., BREGMAN, M., ARAÚJO, D.V., RUFINO, R. **Estimativa de custo da asma em tratamento ambulatorial: estudo com dados de mundo real**. Rev Saude Publica, 52:27. 2018.

DEFRIES, R., PAGIOLA, S. (Coord.). **Analytical Approaches for Assessing ecosystem Condition and Human Well-being**. In: HASSAN, R., SHOLES, R., ASH, N. (Ed.). **Ecosystems and Human Well-being**. Estados Unidos da América: Island Press, 2005. p. 37-71. (Ecosystems and Human Well-being: Current State and Trends, v. 1).

GARROD, D. G., WILLIS, K. 1999. **Economic Valuation of the Environment: Methods and Case Studies**. Environmental and Resource Economics, 21, p. 101–102. 2002. DOI: 10.1023/A:1014547926638

GÓMEZ-BAGGETHUN, E., DE GROOT, R., LOMAS P. L., MONTES, C. **The History of Ecosystem Services in Economic Theory and Practice: From Early Notions to Markets and Payment Schemes**. Ecological Economics, 69(6), P. 1209-1218. 2010. DOI: 10.1016/j.ecolecon.2009.11.007

HAINES-YOUNG, R., POTSCHIN, M. B. **Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure**. 2018.

HANSON, C., RANGANATHAN, J., ICELAND, C., FINISDORE, J., **The corporate ecosystem services review: guidelines for identifying business risk and opportunities arising from ecosystem change**. Version 2.0. Whashington, D.C: World Resources institute. 2012.

IBGE. **Panorama – São Gonçalo do Amarante**. Available at: <https://cidades.ibge.gov.br/brasil/ce/sao-goncalo-do-amarante/panorama>. Accessed on: February 1st of 2021a.

IBGE. **Panorama – Caucaia**. Available at: <https://cidades.ibge.gov.br/brasil/ce/caucaia/panorama>. Accessed on: February 1st of 2021b.

KALLIS, G., GÓMEZ-BAGGETHUN, E., ZOGRAFOS, C. **To value or not to value? That is not the question**. Ecological Economics, 94, p. 97-105. 2013. DOI: 10.1016/j.ecolecon.2013.07.002

KARIMZADEGAN, H., RAHMATIAN, M., FARHUD, D.D., YUNESIAN, M. **Economic valuation ofair pollution health impacts in the Tehran Area**, Iran. Iran. J. Public Health, 20–30. 2008. Available at: http://ijph.tums.ac.ir/index.php/IJPH/article/view/2068.

MILLENNIUM ECOSYSTEM ASSESSMENT. MEA. **Ecosystems and human well-being: a framework for assessment**. Washington, DC: Island Press, 2003.

MESQUITA, K., COLOMBINI, M., DUARTE, G. et al. **Revelando a dermatite atópica no Brasil: um relato da perspectiva da assistência clínica**. J. Bras. Econ. Saúde 11(2):153-60. 2019.

MINISTÉRIO DO MEIO AMBIENTE. MMA. CONSELHO NACIONAL DO MEIO AMBIENTE. CONAMA. **Resolução nº 491, de 19 de novembro de 2018. Dispõe sobre padrões de qualidade do ar**. Available at: http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=740. Accessed on: February 1st of 2021.

NICOLUSSI, F. H., SANTOS, A. P. M., ANDRÉ, S. C. S., VEIGA, T. B., TAKAYANAGUI, A. M. M. **Poluição do ar e doenças respiratórias alérgicas em escolares**. Revista de Saúde Pública, 48(2), p. 326-330. 2014. DOI: 10.1590/S0034-8910.2014048004940

NUTO, S. A. S., FREITAS, R. W. J. F., OLIVEIRA, B et al. **Avaliação de saúde de escolares de duas comunidades no entorno do Complexo Industrial e Portuário do Pecém, Ceará**. In: 4º Congresso Brasileiro de Avaliação de Impacto, 2018, Fortaleza. 4º Congresso Brasileiro de Avaliação de Impacto, p. 1-5. 2018 a.

NUTO, S. A. S., BARREIRA FILHO, E. B., OLIVEIRA, B., et al. **Percepção geral e de saúde de quatro comunidades no entorno do Complexo Industrial e Portuário do Pecém, Ceará**. 4º Congresso Brasileiro de Avaliação de Impacto Ambiental (CABAI). 2018 b.

RIVAS, E., SANTIAGO, J.L., LECHÓN, Y., MARTÍN, F., ARIÑO, A., PONS, J.J., SANTAMARÍA, J.M. **CFD modelling of air quality in Pamplona City (Spain): assessment, stations spatial representativeness and health impacts valuation**. Sci. Total Environ. 649, 1362–1380. 2019. DOI: 10.1016/j.scitotenv.2018.08.315.

SÃO GONÇALO DO AMARANTE (GOVERNO). **Lei Orçamentária Anual. 2018**. Available at: <http://saogoncalodoamarante.ce.gov.br/portal/images/LRF_EXERCICIO2018/LOA2018.PDF>. Accessed on: February 1st of 2021.

SOLÉ, D., WANDALSEN, G. F., CAMELO-NUNES, I. C., et al. **Prevalence of symptoms of asthma, rhinitis, and atopic eczema among Brazilian children and adolescents identified by the International Study of Asthma and Allergies in Childhood (ISAAC), Phase 3.** Jornal de Pediatria, Porto Alegre, v.82, n.5. 2006.TOLAMSQUIM, M.T., MOTTA, R.S., ROVERE, E.L.L., et al. Metodologias de Valoração de Danos Ambientais Causados pelo Setor Elétrico. COPPE/ENERGE/IVIG. Editado pelo Setor de Publicações e Programação Visual/COPPE. 2000.

TOLMASQUIM, M.T. (coord.) (2000) Metodologias de Valoração de Danos Ambientais causados pelo Setor Elétrico. UFRJ; COOPE. Rio de Janeiro. Programa de Planejamento Estratégico. 272 p.173

WANG, J., ZHANG, Y., LI, B., et al. **Asthma and allergic rhinitis among young parents in China in relation to outdoor air pollution, climate, and home environment.** Science of The Total Environment, 751, 141734. 2021. DOI: 10.1016/j.scitotenv.2020.141734.

WORLD HEALTH ORGANIZATION. WHO **Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide.** 22p. 2006. Available at: https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf?sequence=1&isAllowed=y. Accessed on: February 1st of 2021.

IPECE. CEARÁ. **Escolas públicas do Estado do Ceará**. 2019. Available at: http://mapas.ipece.ce.gov.br/i3geo/metadados/Escolas.txt. Accessed on: February 1st of 2021.

IPECE. CEARÁ. **Perfil Básico Municipal 2017 - São Gonçalo do Amarante**. 2017a. Available at: https://www.ipece.ce.gov.br/wp-content/uploads/sites/45/2013/01/Sao_Goncalo_do_Amarante.pdf. Accessed on: March 1st of 2022.

IPECE. CEARÁ. **Perfil Básico Municipal 2017 - Caucaia**. 2017b. Available at: https://www.ipece.ce.gov.br/wp-content/uploads/sites/45/2018/09/Caucaia_2017.pdf. Accessed on: March 1st of 2022.

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AMBIENTE & SOCIEDADE 25 anos 25 años 25 years

SciELO

Avaliação do serviço ecossistêmico de regulação da qualidade do ar: impactos de um complexo industrial do nordeste brasileiro

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Resumo: Este artigo analisa o impacto econômico das emissões de NO2 e PM10 (material particulado) de um complexo industrial no serviço ecossistêmico (SE) de diluição de poluentes na atmosfera. O Complexo Industrial e Portuário do Pecém (CIPP), Brasil, foi adotado como estudo de caso. A avaliação econômica do SE se baseia no aumento dos custos de saúde associados à maior incidência de rinite e eczema atópico em crianças e adolescentes. A população potencial sintomática foi calculada aproveitando sua relação com a concentração de NO2 e PM10. O impacto é monetizado usando o método de custo de reposição, comparando dois cenários: status quo e baixas emissões. As atividades desenvolvidas no CIPP resultam em um aumento de US $ 720 mil por ano nos gastos com saúde para a região. Esses custos representam um aumento de 70% nos custos relacionados às doenças analisadas.

Palavras-chave: Valoração econômica ambiental; qualidade do ar; poluição atmosférica; custos de saúde; método de custo de reposição; complexo industrial.

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Artigo Original

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SciELO

Valoración del servicio ecosistémico de regulación de la calidad del aire: impactos de un complejo industrial del Nordeste de Brasil

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São Paulo. Vol. 25, 2022
Artículo Original

Resumen: Este artículo analiza el impacto económico de las emisiones de NO2 y PM10 (material particulado) de un complejo industrial en el servicio ecosistémico (SE) de la dilución de contaminantes en la atmósfera. Se adoptó como caso de estudio el Complejo Portuario e Industrial de Pecém (CIPP), Brasil. La valoración económica del SE se basa en el aumento de los costes sanitarios asociados a una mayor incidencia de rinitis y eccema atópico en niños y adolescentes. Se calculó la población sintomática potencial aprovechando su relación con la concentración NO2 y PM10. El impacto se monetiza mediante el método del costo de reposición, comparando dos escenarios: statu quo y bajas emisiones. Las actividades desarrolladas en el CIPP resultan en un aumento de US $ 720 mil por año en los costos de salud para la región. Estos costos representan un aumento del 70% en los costos relacionados con las enfermedades analizadas.

Palabras-clave: Evaloración económica ambiental; calidad del aire; Contaminación atmosférica; costos de salud; método de costo de reemplazo; complejo industrial.