

Air Pollution, Health Expenditures, and Respiratory Mortality: An Efficiency Analysis of OECD Countries

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ABSTRACT

Air pollution and environmental problems cause respiratory morbidity and mortality worldwide. This study aimed to evaluate the impact of particulate matter (PM_{2.5}), greenhouse gas emissions, and health expenditures on mortality from respiratory diseases in selected OECD countries. This cross-sectional study included 17 OECD countries with complete data for 2023. An input-oriented Data Envelopment Analysis (DEA) model was used to assess the efficiency of the countries. PM_{2.5} emissions, greenhouse gas emissions (CO₂-equivalent), and per capita health expenditure were used as input variables, while mortality from respiratory diseases (per 100,000 inhabitants) was defined as the output variable. The mean efficiency score was 0.733, and six countries were identified as efficient. Tobit regression results indicated that PM_{2.5} emissions were significantly and negatively associated with super-efficiency scores ($\beta = -0.133$, $p < 0.05$). Health expenditure per capita also showed a negative association ($\beta = -0.000114$, $p = 0.05$), while greenhouse gas emissions were not significantly related to super-efficiency scores ($p > 0.05$). Health expenditures alone may not increase efficiency without effective environmental control strategies. These findings emphasize the importance of integrating environmental policies into health system planning to reduce the burden of respiratory diseases.

Hava Kirliliği, Sağlık Harcamaları ve Solunum Yolu Hastalıklarına Bağlı Mortalite: OECD Ülkelerinin Etkinlik Analizi

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Hava kirliliği ve çevresel sorunlar, dünya genelinde solunum yolu hastalıklarına bağlı morbidite ve mortaliteye neden olmaktadır. Bu çalışma, seçilmiş OECD ülkelerinde ince partikül madde (PM_{2.5}), sera gazı emisyonları ve sağlık harcamalarının solunum yolu hastalıklarına bağlı mortalite üzerindeki etkisini değerlendirmeyi amaçlamıştır. Bu kesitsel çalışma, 2023 yılına ait eksiksiz verileri bulunan 17 OECD ülkesini kapsamaktadır. Ülkelerin etkinliğini değerlendirmek için girdi yönelimli Veri Zarflama Analizi (VZA) modeli kullanılmıştır. PM_{2.5} emisyonları, sera gazı emisyonları (CO₂-eşdeğeri) ve kişi başına sağlık harcaması girdi değişkenleri olarak kullanılırken, solunum yolu hastalıklarına bağlı mortalite (100.000 kişi başına) çıktı değişkeni olarak tanımlanmıştır. Ortalama etkinlik puanı 0,733 olup altı ülke etkin olarak belirlenmiştir. Tobit regresyon sonuçları, PM_{2.5} emisyonlarının süper etkinlik puanları ile negatif yönde ilişkili olduğunu göstermiştir ($\beta = -0,133$, $p < 0,05$). Kişi başına sağlık harcaması da süper etkinlik puanları ile negatif yönde anlamlı ilişkili bulunmuştur ($\beta = -0,000114$, $p = 0,05$), ancak sera gazı emisyonları ile süper etkinlik puanları arasında anlamlı bir ilişki yoktur ($p > 0,05$). Sağlık harcamaları, etkili çevresel kontrol stratejileri olmaksızın tek başına etkinliği artırmayabilir. Bu bulgular, solunum yolu hastalıklarının yükünü azaltmak amacıyla çevresel politikaların sağlık sistemi planlamasına entegre edilmesinin önemini vurgulamaktadır.

INTRODUCTION

Air pollution, particularly fine particulate matter (PM_{2.5}), is closely linked to a range of cardiovascular diseases and respiratory illnesses, such as chronic obstructive pulmonary disease (COPD), asthma, lung infections, and lung cancer (1-3). Recent evidence from a meta-analysis of 50 high-quality studies further demonstrated significant associations between air pollution exposure and respiratory health outcomes, with PM_{2.5} showing a positive association across different age groups (overall OR = 1.26), highlighting the substantial respiratory health burden associated with particulate air pollution (4). Exposure to common air pollutants such as nitrogen dioxide (NO₂), sulfur dioxide (SO₂), ozone (O₃), carbon monoxide (CO), and particulate matter is associated with a higher incidence and greater severity of respiratory disorders. These pollutants may induce oxidative stress, inflammatory responses, and immune system dysfunction in the lungs (3, 5). Even short-term exposure to PM_{2.5} may trigger cardiovascular deaths and events, while long-term exposure further increases the risk and reduces life expectancy. Conversely, reductions in PM levels have been associated with a decrease in cardiovascular mortality in the short term (2).

Increased carbon dioxide (CO₂) emissions resulting from industrial activity and environmental degradation are often accompanied by higher levels of harmful air pollutants, which indirectly contribute to respiratory health problems. In addition, air pollution leads to significant economic costs, including increased healthcare expenses and productivity losses (6, 7).

Evidence from Organisation for Economic Co-operation and Development (OECD) countries shows that increased health spending is associated with lower mortality related to respiratory diseases and improved economic well-being. This emphasizes the importance of adequate health funding in mitigating the broader societal and economic impacts of respiratory health problems (8). However, it remains unclear to what extent healthcare spending may reduce the negative health effects of environmental pollution. Increased healthcare spending is associated with better management of infectious respiratory diseases such as tuberculosis. However, chronic conditions such as COPD may still be prevalent due to factors such as smoking and air pollution (9).

Data Envelopment Analysis (DEA) is used to evaluate the relative efficiency of decision-making units under multiple inputs and outputs. In recent years, DEA has been increasingly applied in environmental performance research, particularly in studies examining ecological and sustainability efficiency across European Union countries (10, 11). In addition, DEA has been successfully applied to assess the efficiency of health systems and healthcare resource allocation in regional and international contexts, demonstrating its suitability for complex, multidimensional performance evaluation (12). Previous studies have primarily examined the direct relationship between air pollution and respiratory diseases (3, 9, 13). However, limited studies have evaluated how countries perform in transforming environmental and economic inputs into favorable respiratory health outcomes (14, 15). Therefore, this study aims to evaluate the impact of PM_{2.5} and greenhouse gas emissions, and per capita healthcare expenditure on mortality from respiratory system diseases in selected OECD countries using an input-oriented CCR DEA model and Tobit regression analysis.

MATERIALS AND METHODS

Study Design

This cross-sectional study aimed to investigate the impact of environmental and economic factors on mortality from respiratory system diseases in OECD countries with complete data availability for the year 2023. A cross-sectional design was selected because the study sought to

assess the relationship between environmental exposures, health expenditure, and respiratory mortality at a single point in time using internationally comparable data available for the same year. The study population consisted of 38 member countries of the OECD. Due to data availability limitations, 17 OECD countries, which had complete data for all study variables, were included in the analysis.

Ethical approval

Ethical approval was not required for this study, as the analysis was based exclusively on anonymized secondary data from the OECD database. The study did not involve human participants, clinical procedures, or the use of identifiable personal data.

Variables

In this study, three input variables were included in the model: PM2.5 emissions (kilogrammes per person) as an indicator of air pollution, greenhouse gas emissions (kilogrammes of CO₂-equivalent per person), and per capita health expenditure adjusted for purchasing power parity (PPP, current USD). The output variable was defined as mortality (deaths per 100,000 inhabitants) from respiratory system diseases measured using the relevant mortality or incidence indicator based on data availability. Respiratory mortality was treated as an undesirable output.

Statistical Analysis

This study investigated the effects of PM2.5 and greenhouse gas emissions, and per capita health expenditure on mortality from respiratory diseases in two stages. First, the suitability of the variables for analysis was evaluated, and then their efficacy and effects were determined.

The analyses were conducted using the R Studio software package. The results obtained from the software program were recorded and saved in Excel format. Spearman correlation coefficients ranged from -0.71 to 0.21. The VIF values were within acceptable limits, indicating that no serious multicollinearity was present. Therefore, no variable reduction or modification was required. The DEA assessed the efficiency of countries in terms of environmental risk factors and health expenditures from respiratory disease mortality.

In this study, an input-oriented CCR model was used because outputs in the health sector are generally difficult to control directly. The input-oriented model aims to minimize inputs while maintaining the current level of outputs. In addition, CCR super-efficiency analysis was performed to assess super-efficiency scores. The Tobit regression analysis was performed to examine the relationship between the input variables and the super-efficiency scores obtained from DEA, and to determine the direction and magnitude of this association. Before conducting the Tobit regression analysis, the Variance Inflation Factor (VIF) test was applied to determine whether multicollinearity existed among the independent variables. The VIF values were found to be within acceptable limits, indicating that there was no serious multicollinearity problem in the model.

RESULTS AND DISCUSSION

Descriptive statistics of the input and output variables are presented in Table 1. Across the 17 countries, the mean health expenditure per capita was 4657 USD, while mean PM2.5 emissions and greenhouse gas emissions were 4.63 kg per person and 7.8 kg CO₂ equivalent per person, respectively. The mean mortality from respiratory system diseases was 66.4 per 100.000 inhabitants. Switzerland had the highest health expenditure, Australia had the highest PM2.5 and greenhouse gas emissions, and Spain had the highest respiratory disease mortality (Table 1).

Table 1. Descriptive statistics of input and output variables across the 17 countries

Input Variables	Max	Min	Mean
Health expenditure per capita (USD)	7929	1846	4657
Air emissions: particulates (PM2.5), kg per person	32.57	0.7	4.63
Greenhouse gas emissions (CO ₂ -eq), kg per person	19.93	4.21	7.8
Output Variable			
Deaths from respiratory diseases (per 100,000 inhabitants)	97.2	36.4	66.4

CO₂-eq, carbon dioxide equivalent; PM2.5, particulate matter with a diameter $\leq 2.5 \mu\text{m}$

Spearman correlation coefficients among the variables ranged from -0.71 to 0.21 (Table 2).

Table 2. Spearman correlation coefficients between variables

Variables	GHG emissions	PM2.5 emissions	Health expenditure	Respiratory deaths
GHG emissions	1	0.21	0.21	0.14
PM2.5 emissions		1	-0.71	-0.14
Health expenditure			1	-0.17
Respiratory deaths				1

GHG, Greenhouse gases, PM2.5, particulate matter with a diameter $\leq 2.5 \mu\text{m}$

Based on the analysis of the 2023 data using the CCR model, the mean efficiency score was 0.733. Among the 17 countries included in the analysis, six were identified as efficient. Australia had the lowest efficiency score (0.236), whereas Switzerland had the highest efficiency score (0.984) among the inefficient countries (Table 3).

Table 3. CCR input-oriented efficiency scores of the countries

Countries	Efficiency Scores	Countries	Efficiency Scores
Germany	1	Czechia	0.636
Hungary	1	Latvia	0.635
Netherlands	1	Austria	0.629
Slovak Republic	1	Luxembourg	0.608
Spain	1	Lithuania	0.402
Turkey	1	Finland	0.333
Switzerland	0.984	Slovenia	0.326
Sweden	0.951	Australia	0.236
Poland	0.718	Average	0.733

Spain was referenced 9 times, followed by Hungary (5), Turkey (4), Germany (4), the Netherlands (3), and the Slovak Republic (1). All six countries identified as efficient were used as reference units by the inefficient countries. Table 4 presents the target input levels required for inefficient countries to reach the efficiency frontier.

Table 4. Efficiency Goals of Inefficient Countries

Countries	GHG emissions		PM2.5 emissions		Health expenditure	
	Current	Target	Current	Target	Current	Target
Switzerland	4.59	4.52	0.7	0.69	7.929	3.990
Sweden	4.21	4	1.35	1.28	6.203	3.012
Poland	8.98	6.44	6.02	3.67	3.124	2.243
Czechia	9.44	6	3.94	2.50	3.942	2.507
Latvia	5.3	3.37	7.68	2.02	2.493	1.585
Austria	7.52	4.73	1.39	0.87	6.360	4.006
Luxembourg	11.68	4.93	1.89	1.15	6.077	3.696
Lithuania	6.25	2.51	3.21	1.29	3.223	1.297
Finland	7.33	2.44	2.34	0.78	5.374	1.791
Slovenia	6.99	2.28	4.36	1.12	4.118	1.343
Australia	19.93	4.70	32.57	2.60	5.778	1.364

GHG, Greenhouse gases; PM2.5, particulate matter with a diameter $\leq 2.5 \mu\text{m}$

Among the 17 countries analyzed, 10 showed increasing returns to scale, 1 showed decreasing returns to scale, and 6 operated under constant returns to scale. The countries operating under constant returns to scale were Germany, Hungary, the Netherlands, the Slovak Republic, Spain, and Turkey. Poland was the only country exhibiting decreasing returns to scale (1.02). In contrast, Australia (0.70), Austria (0.65), Sweden (0.65), Latvia (0.60), Switzerland (0.59), Lithuania (0.43), Slovenia (0.40), Finland (0.40), Czechia (0.93), and Luxembourg (0.74) exhibited increasing returns to scale.

CCR super-efficiency scores were calculated for all 17 countries. According to the CCR input-oriented model, Turkey had the highest super-efficiency score among the six efficient countries and could increase its inputs by 41% while remaining efficient. The remaining efficient countries were Spain (1.274), the Netherlands (1.120), the Slovak Republic (1.068), Germany (1.040), and Hungary (1.004), in descending order of their super-efficiency scores.

Prior to the Tobit regression analysis, variance inflation factor (VIF) values were calculated to assess multicollinearity among the independent variables. The VIF values were 3.83 for greenhouse gas emissions, 3.71 for PM2.5 emissions, and 1.16 for health expenditure per capita, indicating no serious multicollinearity among the variables. Tobit regression analysis was performed to investigate the relationship between the super-efficiency scores derived from the input-oriented CCR DEA model and the input variables. Super-efficiency scores were treated as the dependent variable, while the input variables were included as independent variables. The Tobit regression results showed that the model was statistically significant at the 10% level (Wald = 7.243, $p = 0.064$). PM2.5 emissions were negatively associated with super-efficiency scores and were statistically significant ($\beta = -0.133$, $p < 0.05$). Health expenditure per capita also showed a negative coefficient and was marginally significant ($\beta = -0.000114$, $p = 0.05$). In contrast, greenhouse gas emissions were not statistically significant ($p > 0.05$; Table 5).

Table 5. Tobit Regression Analysis Results

Variable	Coefficient (β)	Std. Error	z value	p value
Intercept	1.998	0.463	4.316	<0.001***
PM2.5 emissions	-0.13	0.056	-2.347	0.01
Air emissions GHG	-0.03	0.038	-0.973	0.33
Health expenditure per capita (USD)	-0.000114	0.000059	-1.937	0.05
Model Statistics				
Log-likelihood = -3.445	Wald-statistic = 7.243	Sigma(scale) = 0.281	p value = 0.064	

GHG, Greenhouse gases; PM2.5, particulate matter with a diameter $\leq 2.5 \mu\text{m}$

This study investigated the relationship between environmental risk factors, health expenditures, and mortality rates from respiratory diseases in selected OECD countries using DEA and Tobit regression analysis. The results showed that PM2.5 emissions were significantly and negatively associated with super-efficiency scores. This finding may reflect that higher levels of particulate pollution reduce the efficiency with which countries translate environmental and economic inputs into positive respiratory health outcomes. Health expenditure per capita also showed a significant negative association with super-efficiency scores, while greenhouse gas emissions were not significantly related to efficiency. In addition, six countries were identified as efficient according to the CCR model.

The negative association observed in this study between PM2.5 emissions and super-efficiency scores is consistent with previous epidemiological studies linking particulate air pollution to adverse respiratory outcomes (16). PM2.5 is a complex pollutant that increases morbidity and mortality from respiratory diseases, including asthma and chronic obstructive pulmonary disease (COPD), and impairs pulmonary function parameters such as FEV1 and FVC

(17, 18). Hu et al. (19) estimated that PM_{2.5} substantially contributed to the global burden of lower respiratory infections in 2019, leading to a large number of deaths (0.7 million) and disability-adjusted life years (37.6 million). These findings are consistent with our results and indicate that reducing PM_{2.5} emissions may improve respiratory health outcomes for the population and enhance the efficiency of national health systems (17, 19). Our study showed a negative relationship between health expenditures and super-efficiency scores. Theoretically, increased healthcare spending can be expected to have a direct and positive impact on overall health outcomes. However, higher health expenditures may reflect a greater disease burden rather than an improvement in the efficiency of the health system. Previous studies investigating the relationship between healthcare expenditures and health outcomes show inconsistent results in the literature (20). Anwar et al. (20) found that increased government health spending in OECD countries was associated with a decrease in infant mortality rates and an increase in life expectancy. However, Al-Azri et al. (21) demonstrated that health investments are an effective tool in reducing maternal and child mortality, but had no significant effect on deaths caused by non-communicable diseases. Countries with higher rates of chronic respiratory diseases or aging populations may have allocated more resources to healthcare without achieving improvements in mortality rates. In addition, health spending may have focused on treatment rather than prevention. Therefore, the limited impact of increased healthcare expenditures on mortality outcomes may be attributed to uncontrolled environmental risk factors, such as air pollution, and the prioritization of curative over preventive health strategies.

According to the Tobit regression model, the lack of a statistically significant association between greenhouse gas emissions and efficiency scores may be explained by several factors in our study. PM_{2.5} has well-established direct short-term effects on respiratory mortality (16). Beyond their potentially limited short-term effects on respiratory health, greenhouse gases contribute to long-term climate change, which may worsen air quality and increase aeroallergen exposure over time, thereby increasing the risk of respiratory diseases. Reducing greenhouse gas emissions and implementing adaptation strategies are critical to mitigating these long-term impacts on respiratory health (22, 23).

CONCLUSION AND RECOMMENDATIONS

In conclusion, the findings of this study have important consequences for public health policies. First, reducing exposure to fine particulate matter is a main objective for governments aiming to improve respiratory health outcomes. Policies targeting industrial emissions, transportation pollution, and energy production can significantly reduce PM_{2.5} levels and associated health risks. Second, health expenditures alone may not be sufficient to reduce deaths related to respiratory diseases unless supported by effective environmental and preventive health strategies. Therefore, integrating environmental policies with health planning can provide a more effective approach to improving population health outcomes. Environmental health policies may include changing energy sources, limiting the use of solid fuels, promoting public transportation, improving fuel quality, using alternative and cleaner fuels, implementing traffic restrictions, and promoting low- or zero-pollution vehicles such as electric vehicles (24).

This study combines DEA with Tobit regression modeling to provide a comprehensive assessment of the efficiency with which countries translate environmental and economic inputs into health outcomes. In addition, the use of internationally comparable OECD data increases the reliability and comparability of the results.

This study has several limitations. The analysis was conducted using the most recent available cross-sectional data from 2023 for all input and output variables. Data from 2023 were selected to avoid potential confounding effects related to the COVID-19 pandemic and to ensure the use of the most recent and comparable post-pandemic data. However, this may limit the ability

to assess temporal relationships between pollution exposure and respiratory mortality. Second, the analysis included only 17 OECD countries due to data availability constraints, which may limit the generalizability of the findings.

Author contributions:

ZÇ: Conceptualization, Investigation, Methodology, Validation, Visualization, Writing-original draft, Writing-review&editing; FS: Conceptualization, Investigation, Methodology, Writing-review&editing; FA: Conceptualization, Investigation, Formal analysis, Methodology, Writing-review&editing. All authors read and approved the final manuscript.

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