

## Economic Valuation of Transport-Related $NO_2$ and $SO_2$ Exposure on ARI Prevalence Trends: A Comparative Analysis of Environmental Statistics and Indonesian Health Profiles (2018-2023)

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### ABSTRACT

Air pollution from road transport significantly contributes to Acute Respiratory Infection (ARI) morbidity in Indonesia. Air pollution originating from road transportation is a major contributor to Acute Respiratory Infection (ARI) morbidity in Indonesia. This study analyzes trends between transport exposure indicators and ARI prevalence while quantifying economic burden using panel data (2018–2023). Secondary data on motorized vehicle volume, Air Pollutant Standard Index (ISPU), and provincial ARI cases were analyzed using a Fixed Effect regression model, controlling for population density and regional GDP per capita. Economic valuation was conducted using the Cost of Illness (COI) approach. ISPU and vehicle volume showed a statistically significant positive association with ARI cases ( $p < 0.001$ ). A 1% increase in ISPU and vehicle volume linked to 0.456% and 0.287% ARI increases, respectively. Total COI reached Rp 42.63 Trillion, with 74.3% (Rp 31.68 Trillion) attributable to transport pollution. Transport pollution drives ARI morbidity and substantial economic costs. Findings urge emission controls, sustainable transport policies, and external cost internalization to reduce public health burdens.

**Keywords:** Air Pollution; Transport Emissions; ARI; Cost of Illness; Economic Valuation; Indonesia

### 1. Introduction

Air pollution, particularly in densely populated urban areas, has become a critical public health and environmental challenge at both global and national levels. In the context of Indonesia, the road transport sector stands out as a dominant contributor to atmospheric contamination [1, 2]. Rapid population expansion coupled with accelerating urbanization has resulted in a significant surge in motorized vehicles. This phenomenon is directly linked to an increased discharge of hazardous

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pollutants, including particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), nitrogen oxides (NO<sub>x</sub>), and sulfur dioxide (SO<sub>2</sub>) [1]. These airborne contaminants not only degrade the environment but also act as a primary trigger for various adverse health outcomes, predominantly affecting the respiratory system [2].

Acute Respiratory Infection (ARI), known as ISPA in Indonesia, represents one of the most substantial disease burdens nationwide, consistently ranking highest in terms of National Morbidity based on Ministry of Health data. While ARI stems from complex etiologies, including viral and bacterial infections, sustained exposure to transport-related air pollution—reflected in elevated ISPU values—has been identified as a critical environmental risk factor. This exposure exacerbates symptoms and drives up the incidence of the disease [3].

Numerous studies globally have established a robust correlation between air contamination and detrimental health impacts, which subsequently translate into considerable economic costs. The economic valuation of health losses attributable to pollution serves as a vital policy instrument, as it allows for the quantification of external costs generated by economic activities, such as transportation, that are typically not accounted for in market prices [4]. These costs encompass direct medical expenses (treatment, hospitalization), indirect costs stemming from lost work or school days (morbidity), and losses associated with premature fatalities (mortality).

Despite this relevance, previous studies in Indonesia, mostly covering the period up to 2020, remain limited in integrating environmental statistics—such as vehicle volume and ISPU—with public health data on ARI prevalence within a consistent analytical framework for the more recent period of 2018–2023 [5, 6, 7]. This unified data approach is essential to provide solid empirical evidence regarding the socio-economic consequences of existing transport and environmental policies.

Accordingly, this study pursues two main objectives: (1) to analyze comparative trends between transport-related exposure indicators and ARI prevalence during 2018–2023; and (2) to estimate the economic burden of transport-related ARI cases using the Cost of Illness approach. The findings generated from this research are anticipated to offer evidence-based recommendations for policymakers in developing sustainable transport strategies and implementing more effective air pollution control measures. This study hypothesizes that higher transport-related air pollution exposure, reflected by ISPU levels and vehicle volume, significantly increases ARI prevalence and imposes substantial economic costs.



## 2. Materials and Method

### *Research Design*

This study employs a quantitative comparative-econometric design utilizing a panel data (pooled cross-sectional time series) approach. This methodology was selected for its capacity to facilitate a more robust analysis of the causal relationship between environmental/transportation exposure variables (independent variables) and health outcome variables (dependent variables). The panel dataset consists of 34 provinces observed over six years (2018–2023).

### *Sources and Types of Secondary Data*

The data analyzed in this research consists exclusively of official secondary data sourced from Indonesian government institutions spanning the 2018 to 2023 period.

**Table 1. Sources, Variables, and Types of Secondary Data (2018–2023)**

Variable	Key Indicators	Official Data Source	Data Period
Independent Variables (Exposure)	Motorized Vehicle Volume (units)	BPS: Statistics of Transportation & Environment	2018–2023
	Fuel Consumption (liters)	BPS: Environmental Statistics	2018–2023
	Annual Average Air Pollutant Standard Index (ISPU)	KLHK: Air Quality Index Report	2018–2023
Dependent Variable (Health Impact)	ARI Cases (Morbidity, Per Province)	Ministry of Health: Indonesian Health Profile	2018–2023
Control Variables	Population Density, Regional GDP per Capita	BPS: Population & Economic Statistics	2018–2023



## Data Analysis Model

### Trend and Correlation Analysis

Descriptive analysis and data visualization techniques were employed to observe the developmental trends of vehicle volume, ISPU levels, and ARI prevalence at both national and provincial levels. Subsequently, the Pearson correlation coefficient ( $r$ ) was computed to assess the magnitude and direction of the linear association between the average annual ISPU and the corresponding number of ARI cases per province.

### Panel Data Econometric Model

To empirically test the hypothesized causal relationship, a panel data regression model was utilized, formalized as follows:

$$\text{Ln}(\text{ARI}_{it}) = \beta_0 + \beta_1 \text{Ln}(\text{ISPU}_{it}) + \beta_2 \text{Ln}(\text{VehicleVolume}_{it}) + \beta_3 \text{Control}_{it} + \alpha_i + \delta_t + \epsilon_{it}$$

$\text{ARI}_{it}$ : The recorded number of Acute Respiratory Infection cases in Province  $i$  in year  $t$ .

$\text{ISPU}_{it}$ : The Air Pollutant Standard Index value in Province  $i$  in year  $t$ .

$\text{VehicleVolume}_{it}$ : The aggregate volume of motorized vehicles in Province  $i$  in year  $t$ .

$\text{Control}_{it}$ : Control variables (e.g., Population Density, Regional GDP per Capita).

$\alpha_i$ : Provincial Fixed Effect (used to control for time-invariant, unobserved heterogeneity across provinces).

$\delta_t$ : Time Effect (used to control for macro-environmental or economic shocks that are uniform across all provinces over time).

$\epsilon_{it}$ : The stochastic Error Term.

The appropriate model specification either Common Effect, Fixed Effect, or Random Effect was determined through standard diagnostic tests, including the Chow test, the Hausman test, and the Lagrange Multiplier (LM) test [8].



### *Economic Valuation: The Cost of Illness (COI) Method*

The economic valuation was executed using the Cost of Illness (COI) methodology. This approach estimates the total economic expenditure resulting from ARI cases that are attributable (or assumed to be linked) to transport-related pollution exposure. The COI framework involves the estimation of both direct costs and indirect costs [9].

**Direct Costs:** These encompass expenditures related to medical treatment, pharmaceuticals, outpatient visits, and hospitalization incurred due to ARI cases. Cost data were derived from established national health insurance (BPJS) standard rates or official average cost-per-case data published by the Ministry of Health or reputable Indonesian health economics studies [10].

**Indirect Costs:** These cover productivity losses resulting from missed work days (or school days) due to illness or caregiving responsibilities. The estimation of this component was based on the Regional Gross Domestic Product (RGDP) per capita as a proxy for the value of lost working days.

The annual Total COI estimation was computed using the following formula:

$$COI_t = (\text{Direct Costs}_t + \text{Indirect Costs}_t) \times \text{ARI Cases}_t$$

The proportion of total losses specifically attributable to transportation exposure was determined by applying the econometric regression coefficients ( $\beta_1$  and  $\beta_2$ ), which quantify the percentage increase in ARI cases associated with increases in ISPU and Vehicle Volume.

## 3. Result

### *Trends in Environmental and Health Statistics (2018–2023)*

The volume of motorized vehicles in Indonesia exhibited a consistent upward trend from 2018 to 2023, interrupted only by a dip in 2020 due to social restrictions implemented during the COVID-19 pandemic [5]. This growth was predominantly driven by two-wheeled vehicles. Correspondingly, the annual average Air Pollutant Standard Index (ISPU) in major metropolitan areas consistently indicated suboptimal conditions, frequently falling into the "Moderate" or "Unhealthy" categories, particularly within provinces characterized by high traffic density, such as West Java, DKI Jakarta, and Banten [6].



**Table 2. Summary Data of National Average ISPU and ARI Cases Trends (2018–2023)**

Year	National Average ISPU	Total ARI Cases (Millions)
2018	75	18.2
2019	81	20.4
2020	65	16.1
2021	68	17.5
2022	84	24.0
2023	87	25.6
Total	121.8	

Source: BPS (2024), KLHK (2024), Ministry of Health (2024) – Data Processed

The national ARI Case Trend mirrored the pattern observed in Vehicle Volume and ISPU, exhibiting a decline during the 2020–2021 pandemic period followed by a significant surge in 2022–2023. This notable post-pandemic rebound suggests that the intensified pollutant exposure, concomitant with the normalization of transportation activities, is a substantial contributor to the respiratory disease burden [7].

#### *Panel Data Econometric Model Results*

Based on standard statistical diagnostics (Chow and Hausman tests), the Fixed Effect (FE) Model was determined to be the most appropriate estimation technique. The FE model effectively controls for time-invariant, province-specific characteristics (such as stable geographical features or entrenched health cultures) that could otherwise bias the results.

**Table 3. Fixed Effect Panel Regression Results for ARI Cases (2018–2023)**

Variable	Coefficient	Std. Error	t (df: 197)	p-value	Partial Eta <sup>2</sup>
Ln(ISPU)	0.456	0.089	5.124	< .001	0.117
Ln(Vehicle Volume)	0.287	0.051	5.627	< .001	0.138
Ln(Population Density)	0.112	0.065	1.723	.086	0.015
Ln(RGDP per Capita)	-0.058	0.044	-1.318	.189	0.009
Constant	3.481	1.152	3.022	.003	



R-squared (Within)	0.782	
F(4, 197)	176.45	< .001

Note: The Dependent Variable is Ln(ARI Cases). Significance level set at  $\alpha = 0.05$ .

The regression results indicate that the variables Ln(ISPU) and Ln(Vehicle Volume) both maintain a positive and highly statistically significant relationship ( $p < .001$ ) with Ln(ARI Cases). The coefficient of 0.456 for Ln(ISPU) implies that a 1% increase in the annual average ISPU is associated with a 0.456% rise in ARI cases, holding other variables constant. The coefficient of 0.287 for Ln(Vehicle Volume) indicates that a 1% increase in the volume of motorized vehicles is associated with a 0.287% increase in ARI cases. The effect size, measured by the partial eta squared, suggests that ISPU and Vehicle Volume exert a moderate yet substantial influence in accounting for the variation in ARI cases across provinces and over time. This finding corroborates external research highlighting that air pollution and transportation activities are key drivers of respiratory morbidity in Indonesia [11].

#### Economic Valuation (Cost of Illness)

The COI estimation was calculated using the aggregate number of ARI cases (121.8 Million cases) during the 2018–2023 period and the estimated cost per case (Asri & Nurjana, 2023), adjusted for inflation.

Estimated Cost Per Case (Average Period 2018–2023):

- Direct Costs (Treatment/Outpatient): Rp 200,000 per case.
- Indirect Costs (Productivity Loss): Rp 150,000 per case (Based on an assumption of an average of three lost workdays per ARI case, following estimates commonly used in Indonesian health economic studies)

**Table 4. Estimated Total Cost of Illness (COI) Due to ARI (2018–2023)**

Cost Type	Estimated Cost Per Case (Rp)	Total Cases (Millions)	Estimated Total Cost (Trillion Rupiah)
Direct Costs	200,000	121.8	24.36
Indirect Costs	150,000	121.8	18.27
Total COI	350,000	121.8	42.63

Source: Researcher's calculations based on Ministry of Health (2024) data and health cost studies [10].

The total estimated economic loss (COI) due to ARI over the five-year period (2018–2023) amounts to approximately Rp 42.63 Trillion. Based on the regression outcomes, since  $\ln(\text{ISPU})$  and  $\ln(\text{Vehicle Volume})$  have a combined highly significant coefficient of 0.743 (0.456 + 0.287), it can be conservatively assumed that approximately 74.3% of the variation in ARI cases can be conservatively attributed to transport-related exposure based on estimated elasticities, rather than representing a direct causal proportion (assuming a smaller net impact from other control variables). Applying this ratio to the economic valuation:

Economic Valuation Attributable to Transportation Exposure: Rp 42.63 Trillion  $\times$  74.3%  $\approx$  Rp \*\* 31.68 Trillion\*\*



**Figure 1. Minimum Economic Valuation of Transport-Attributed ARI (2018-2023)**

This figure represents the minimum estimated cost borne by the Indonesian society due to ARI, specifically triggered by transport-related pollution exposure during the 2018–2023 period.



## 4. Discussion

### *Close Link between Transport Emissions and ARI Morbidity*

The findings of this study conclusively demonstrate that indicators of transport-related exposure specifically, increased vehicle volume and higher ISPU values maintain a statistically significant and positive relationship with the prevalence of ARI cases at the provincial level. This outcome aligns with the extensive global scientific literature that widely recognizes air pollution, particularly PM<sub>2.5</sub> and NO<sub>x</sub> predominantly originating from vehicular emissions, as a primary environmental risk factor for both acute and chronic respiratory illnesses [12].

The significant regression elasticity coefficients (0.456 for ISPU and 0.287 for Vehicle Volume) indicate that policies centered on emission control and reducing the number of vehicles on public roads would have a substantial and immediate impact on alleviating the burden of ARI cases. While ISPU data inherently aggregates pollutants from various sources, the sharp increase in ARI cases during 2022–2023, coinciding with the post-pandemic resumption of normal activities and a return to pre-pandemic vehicle volumes, strongly implicates the dominant role of the transport sector [2].

### *Economic Implications for Transport Policy*

The economic valuation figure of Rp 31.68 Trillion, attributed to transport-related health impacts over the last five years (2018–2023), represents an exceedingly substantial amount. This valuation, despite being calculated using the COI method – which tends to underestimate total losses by excluding psychosocial costs or the Value of Statistical Life (VSL) provides robust empirical evidence crucial for policy formulation [4].

This substantial loss figure must be perceived as an external cost imposed upon society and the healthcare system, which ought to be internalized by the transport sector through appropriate policy instruments. This concept of external costs is fundamental in environmental and health economics. For instance, this cost can serve as a strong justification for:

- The implementation of carbon taxes or pollution taxes on fuel and older vehicles.
- Significant investments in electric or zero-emission public transport infrastructure.
- Financial incentives to promote the adoption of electric vehicles or cycling.



By juxtaposing these health-related economic losses against the budgets allocated for transport infrastructure development, governments can undertake more realistic and holistic cost-benefit analyses. Such analyses would ensure that the economic benefits of development are appropriately balanced against the generated public health detriments [1].

#### *Research Limitations*

This study possesses several inherent limitations. Firstly, the reliance on aggregated secondary data at the provincial level may obscure the heterogeneity of data at finer geographical scales (cities or districts), where pollution exposure could be considerably higher. Secondly, the Cost of Illness (COI) method is inherently a conservative approach. It does not account for welfare losses (e.g., Willingness to Pay / WTP) to avert illness or the moral costs (suffering) associated with disease, thereby implying that the true total economic cost is likely much greater [12]. Thirdly, although the regression model controlled for provincial fixed effects, there remains a potential for omitted variable bias from unmeasured factors, such as localized meteorological conditions or individual smoking habits.

## 5. Conclusions

This study concludes that transport-related exposure, as reflected by ISPU levels and vehicle volume, has a significant and positive association with ARI prevalence in Indonesia during the 2018–2023 period. The panel data econometric results confirm that transportation-influenced environmental indicators are strong predictors of ARI morbidity. Furthermore, the economic valuation using the Cost of Illness (COI) method indicates that transport-related air pollution generates a substantial economic burden on public health, underscoring the urgent need for sustainable transport policies. These findings demonstrate that unsustainable transport practices impose considerable external costs on Indonesia's economy and society.



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