

## RESEARCH ARTICLE

<https://doi.org/10.46488/NEPT.2026.v25i04.D1930>

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# The Value of a Statistical Life of Urban Air Pollution in Ho Chi Minh City, Vietnam

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## ARTICLE HISTORY

Received: 16-04-2026

Revised: 01-06-2026

Accepted: 05-06-2026

## KEYWORDS

Value of statistical life  
Willingness to pay  
Air pollution  
Binary logistic model  
Contingent valuation survey  
Urban environmental quality  
Pollution mitigation policies

## CITE THIS ARTICLE

Nguyen, T.T.M., Ho Ky, Q.M. and Tri, D.Q. 2026. The value of a statistical life of urban air pollution in Ho Chi Minh City, Vietnam, *Nature Environment and Pollution Technology*, 25(4), D1930. <https://doi.org/10.46488/NEPT.2026.v25i04.D1930>

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## ABSTRACT

Although the trade-off between income and environmental quality has received increasing attention in recent years, empirical evidence on the Value of a Statistical Life (VSL) associated with air pollution in Vietnam remains limited. This study addresses this gap by estimating the willingness to pay (WTP) and VSL associated with reducing air pollution-related mortality risks in Ho Chi Minh City, one of Vietnam's largest and most densely populated metropolitan areas. Using primary data from a contingent valuation survey (), evaluated through the Turnbull lower-bound estimator along with chi-square analysis and binary logistic regression, we examine the economic valuation of mortality risk reduction and its underlying determinants. The empirical results reveal a mean individual WTP of 17,900 VND per person for a 1/10,000 mortality risk reduction, translating to an individual VSL of approximately USD 6,920 per statistical life saved. When aggregated across the adult population of Ho Chi Minh City, the total economic benefit reaches an aggregate population WTP of about USD 6.57 million. Crucially, over 70% of respondents declined to pay, primarily due to severe household income constraints. Socioeconomic characteristics—including income, age, education, and residential location—were significantly associated with WTP decisions, though the strength of these associations was relatively weak. In addition, the logistic regression analysis highlighted that respondents' trade-off preferences between health and income, and self-reported respiratory conditions, significantly influenced respondents' decision to accept income reductions in exchange for improved environmental quality. The model exhibited satisfactory predictive performance, achieving an AUC above 0.81, overall classification accuracy exceeding 74%, specificity above 79%, and sensitivity above 68%. These findings provide crucial empirical insights into stated-preference valuation under tight budget constraints in a developing-country context, offering valuable evidence to support urban air pollution mitigation policies and health benefit assessments.

## 1. INTRODUCTION

Air pollution in developing countries, particularly in densely populated cities, has recently become a serious concern. In Ho Chi Minh City, Vietnam, the average concentration of PM<sub>2.5</sub> from 2013 to 2017 was five times higher than the World Health Organization (WHO) standard, while PM<sub>10</sub> levels were also approximately five times above the national standard for ambient air quality (EPAVN 2023, IQAir 2024, Vu et al. 2021, WHO 2021). Additionally, air pollution accounts for around 13% of deaths in Ho Chi Minh City, with the majority of these fatalities happening in the city center (Loan 2018).

Environmental quality, particularly ambient air quality, is a non-market good whose economic value is commonly assessed using individuals' willingness to pay (WTP) for environmental improvements (Baker & Ruting 2014, Sajise et al. 2021). Previous studies have reported substantial variation in WTP across countries and socioeconomic contexts. In Pakistan, respondents were willing to pay an average of USD 9.86 per month (approximately 1.3% of household income) for improved air quality, with more than 90% expressing a willingness to contribute (Akhtar et al. 2017). Similarly, a survey of 3,000 urban residents in China estimated an average WTP of approximately USD 10 per person per year (Guo et al. 2020). In Vietnam, WTP estimates for air-quality improvement have generally been lower. Residents of Ho Chi Minh City were found to be willing to pay between USD 0.73 and 1.08 per person per month, while households in Hanoi reported an average WTP of USD 3.58 per month (Le & Bui 2020). Another study in Hanoi estimated that households were willing to allocate up to 0.5% of their total income to improve air quality (Nguyen & Le 2019). Previous research has identified several determinants of WTP for environmental improvement, including education, occupation, residential location, and perceived environmental conditions (Junlin et al. 2024, Xiong et al. 2018). In the Vietnamese context, income, educational attainment, literacy, and financial capacity have consistently been reported as the primary factors influencing individuals' willingness to pay for better environmental quality (Le & Bui 2020).

Given the potentially severe health and mortality impacts of environmental degradation, the Value of a Statistical Life (VSL) has become a widely used framework for quantifying mortality risks by examining the trade-offs individuals make between income and reductions in the probability of death (Andersson & Treich 2013, Colmer 2020). Although VSL has been extensively investigated in developed countries, empirical studies linking VSL directly to pollution-related risks remain relatively limited in developing economies, including Vietnam. One of the few studies in the region estimated the VSL associated with mortality risks from water-pollution-related diarrheal diseases in Laos and Vietnam (Eiji et al. 2012). More recently, a study evaluating the health benefits of public transportation in Hanoi in the context of fine particulate matter (PM<sub>2.5</sub>) pollution estimated a VSL of approximately USD 1.6 million per person by transferring VSL values from Taiwan and adjusting them using income-based conversion factors (Trung & Tri 2022).

Although several studies have estimated willingness to pay (WTP) and the value of a statistical life (VSL) in major Vietnamese cities such as Hanoi and Ho Chi Minh City (Le & Bui 2020, Nguyen & Le 2019), limited attention has been

given to integrating non-parametric and parametric approaches within a unified valuation framework. This study addresses this gap by combining the Turnbull non-parametric estimator with binary logistic regression. To the best of our knowledge, the application of this integrated framework to air-pollution-related VSL estimation remains largely unexplored in developing-country contexts, including Vietnam. The Turnbull estimator provides a conservative, distribution-free estimate derived directly from the observed bid-response data (Haab & Connell 2002), thereby reducing reliance on restrictive distributional assumptions. Complementarily, the binary logistic model enables the identification of socioeconomic and health-related determinants underlying respondents' willingness to pay. By integrating these two approaches, the study not only generates a robust VSL estimate for Ho Chi Minh City but also provides insights into the factors shaping individual risk-reduction preferences in an urban environment affected by air pollution.

Therefore, this study aims to estimate the VSL associated with air pollution in Ho Chi Minh City, Vietnam, using WTP, defined as the monetary amount a person would trade to reduce their annual mortality risk by one unit. The results can support estimation of the social VSL in large urban areas in Vietnam and provide a basis for decision-makers to determine the financial resources required for air-quality protection and improvement projects.

## 2. MATERIALS AND METHODS

### 2.1. Materials

#### 2.1.1. Study Area

Ho Chi Minh City (HCMC) is located in southern Vietnam between 10°10'–10°38' N and 106°22'–106°54' E. As the country's largest economic center, the city serves as a major transportation hub linking surrounding provinces, an international gateway, and a strategic transition zone between the Southeast Region and the Mekong Delta.

Ambient air quality in HCMC is monitored through a network of environmental monitoring stations distributed across the city. Recent assessments indicate that air pollution is primarily driven by particulate matter. Concentrations of Total Suspended Particulates (TSP) and PM<sub>10</sub> have shown increasing trends, particularly in densely populated areas, industrial zones, seaports, and mining sites. More importantly, PM<sub>2.5</sub> concentrations at several traffic and industrial monitoring stations exceeded national standards by 1.1–4.6 times (Phan 2025).

Industrial activities constitute an important source of air pollution in HCMC. Major emission sources include clinker and cement production facilities, chemical and

fertilizer plants, petrochemical processing facilities, and industries operating large-scale boilers. In terms of emission loads, the textile and food-processing sectors are among the largest contributors. The textile industry alone accounts for approximately 37% of TSP emissions and 41% of PM<sub>2.5</sub> emissions, largely due to intensive fuel consumption (e.g., LPG, fuel oil, diesel oil, firewood, and biomass briquettes) and the release of fabric and fiber dust. In addition, textile dyeing and finishing processes generate substantial emissions of non-methane volatile organic compounds (NMVOCs) through activities such as sizing, scouring, bleaching, dyeing, and finishing (DONRE 2021).

Transportation represents the dominant source of air pollution in the city. According to DONRE (2021), the transport sector contributes approximately 99%, 97%, 93%, 78%, 23%, 64%, and 45% of total emissions of CO, NMVOCs, NO<sub>x</sub>, SO<sub>2</sub>, TSP, CH<sub>4</sub>, and PM<sub>2.5</sub>, respectively. Road transport, particularly motorcycles, accounts for nearly 90% of transport-related emissions and is responsible for approximately 75% of transport-generated PM<sub>2.5</sub> emissions. River and seaport activities contribute around 24% of PM<sub>2.5</sub> emissions, whereas aviation contributes only about 1%, and emissions from railway and bus terminal operations remain negligible (DONRE 2021).

### 2.1.2. Sample Size

To determine the minimum required sample size for a large population, Cochran's formula was adopted. Assuming that a proportion of the population would be willing to reduce income to lower the mortality risk from air pollution, the sample size was calculated using Eq. (1) (Daniel & Cross 2013, Singh & Masuku 2013).

$$n = \frac{z^2 * p (1 - p)}{\varepsilon^2} \quad \dots(1)$$

where  $z$  is the corresponding  $z$ -score value;  $\varepsilon$  is the margin of error;  $p$  is the proportion of the selected population. At a 95% confidence level and 5% margin of error, with a selected-population proportion of 50% to achieve the highest minimum sample size, the minimum required sample size is 385.

The study employed a convenience sampling strategy via an online survey. To compensate for potential non-probability sampling bias, a larger sample of over 1,000 valid responses was collected via digital platforms and community networks in Ho Chi Minh City between April 2024 and March 2025. Of the 1,007 questionnaires collected, 879 valid responses were retained for analysis. The sample was predominantly urban, with 85% of respondents residing in central urban districts. The average monthly income was approximately VND 10 million (USD 380), and 70% of respondents reported

monthly incomes below VND 20 million (USD 760), broadly consistent with official statistics for Ho Chi Minh City (Vietnam General Statistics Office 2025). More than 50% of respondents held a university degree or higher, exceeding the citywide average of 15–27% reported in previous studies and official sources (Le 2018, Thanh 2025). This difference likely reflects the online recruitment strategy, which tends to attract individuals with higher educational attainment and greater engagement with environmental issues. While this may limit the representativeness of the sample, it is consistent with the increasing adoption of digital platforms and the city's ongoing digital transformation initiatives (Thanh 2025).

## 2.2. Methods

The methodology and research design are illustrated in Fig. 1.

### 2.2.1. Contingent Valuation Method

The Contingent Valuation (CV) method employs a structured survey to elicit respondents' willingness to pay (WTP) for a specified environmental improvement. First introduced by Ciriacy-Wantrup (1947), the method has been widely applied in environmental valuation, including studies of environmental quality, ecosystem services, and waste management, and has demonstrated satisfactory reliability in estimating non-market values (Bodah et al. 2022, Hoevenagel 1994, Perni et al. 2021, Tang et al. 2022, Thormann & Wicker 2021). In dichotomous-choice CV surveys, respondents are presented with a bid amount and asked whether they would be willing to pay that amount. Consequently, individual WTP is represented as an interval bounded by the respondent's acceptance or rejection of successive bid levels.

To reduce the potential for hypothetical bias and WTP overestimation, particularly in the valuation of public goods (Andersson & Treich 2013, Biaisue 2012), the questionnaire incorporated measures of response certainty and consistency (Hoyos & Mariel 2010, Sajise et al. 2021, Sundström & Andersson 2009). The survey consisted of 35 questions (H1–H35) organized into five sections. The first section included four questions designed to assess respondents' perceptions of air-pollution risks and their understanding of pollution sources. The second section comprised 14 questions addressing self-reported health conditions and symptoms potentially associated with urban air pollution. The third section contained three questions examining respondents' preferences regarding trade-offs between income and health; responses in this section were also used to identify potentially inconsistent answers. The fourth section included eight closed-ended valuation questions related to a hypothetical air-pollution mitigation program. Under this scenario, the program was assumed to reduce the mortality risk from 48 to 47 deaths per 10,000



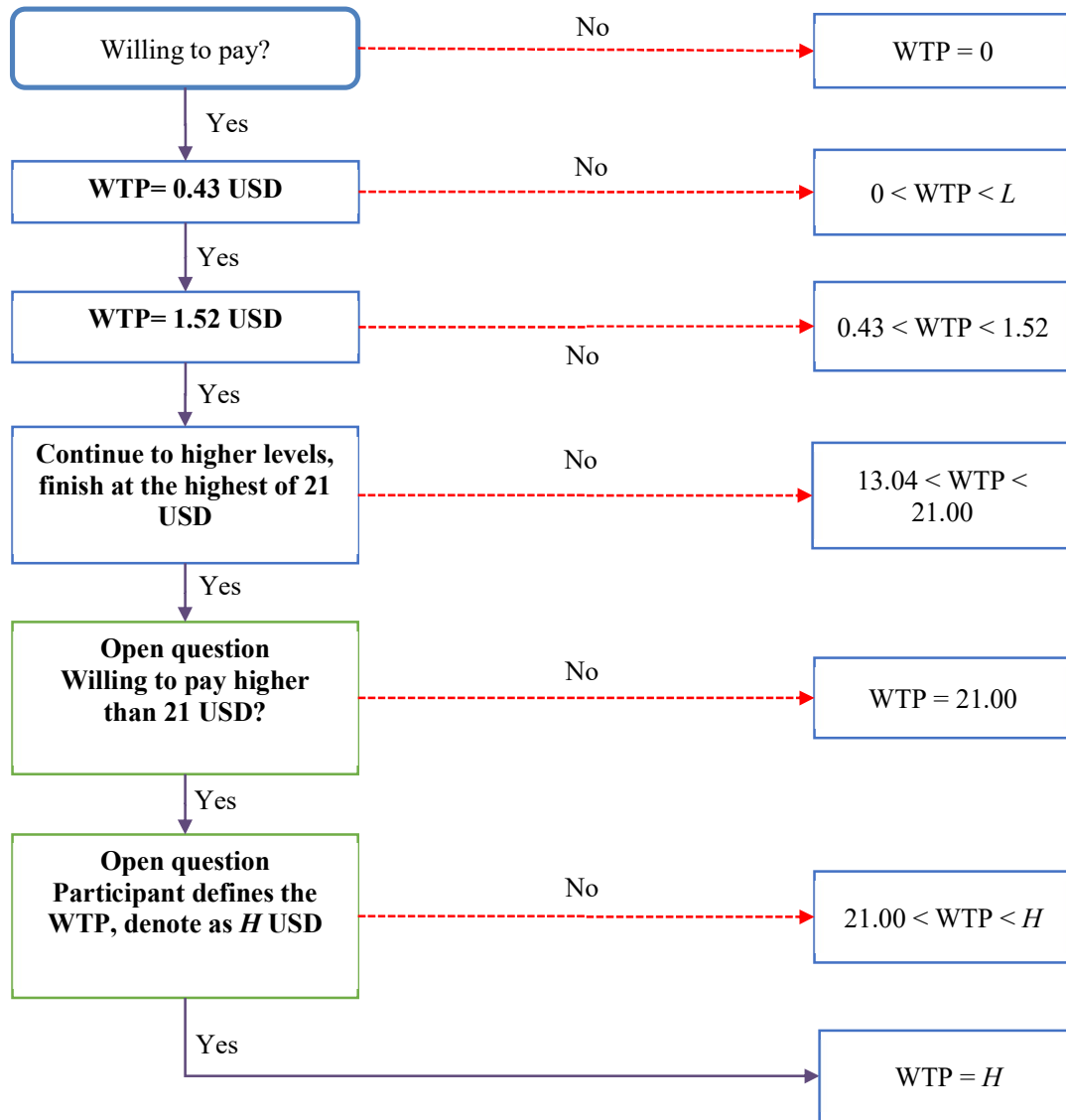


Fig. 2: Contingent valuation survey design.

question (H25) is the dependent variable; therefore, the formula is as follows:

$$P(H_{25} = 1) = \frac{e^{(\beta_0 + \sum_{i=1}^{24} \beta_i H_i)}}{1 + e^{(\beta_0 + \sum_{i=1}^{24} \beta_i H_i)}} \quad \dots(3)$$

Where  $P(H_{25} = 1)$  is the probability that H25 takes a value of 1. H25 takes one of two values: 0 (disagree) or 1 (agree), and  $\beta_i$  is the corresponding parameter of the independent variable  $H_i$ , where  $i$  ranges from 1 to 24.

The logistic regression model was assessed for accuracy, reliability, and sensitivity using the parameters in Table 1 (Criado & Veronesi 2013).

TN and TP are “True Negative” and “True Positive,” respectively. They occur when the predicted value is identical to the actual observation. FN and FP are “False Negative” and “False Positive,” respectively, and occur when the predicted and actual values differ. ON is observed negative, and OP is observed positive.

Table 1: Model evaluation parameters.

|                    | Modeled observation |    | Total        |
|--------------------|---------------------|----|--------------|
|                    | 0                   | 1  |              |
| Actual observation | 0                   | 1  |              |
|                    | TN                  | FP | ON = TN + FP |
|                    | FN                  | TP | OP = FN + TP |

(Note: T = True, F = False, N = Negative, P = Positive, O = Observed)

The evaluation parameters are calculated as follows:

$$\text{Accuracy: CCR} = (\text{TN} + \text{TP})/n \quad \dots(4)$$

$$\text{Sensitivity: TPR} = \text{TP}/\text{OP} \quad \dots(5)$$

$$\text{Specificity: SPC} = \text{TN}/\text{ON} \quad \dots(6)$$

### 2.2.3. Non-parametric Estimation Methods

- WTP estimation using the Turnbull lower-bound non-parametric estimator

Non-parametric estimation is widely applied in recent studies to estimate WTP values for non-market goods (Giolo 2004, Hutchinson et al. 2001, Loureiro et al. 2004, Ranneby & Yu 2011). The method is described using a sample of  $T$  individuals who are offered one of  $B$  monetary amounts, denoted  $B_j$  (where  $B_1 < B_2 < \dots < B_M$ ). The willingness to pay ( $\text{WTP}_i$ ) for each individual  $i$  is modeled as a random variable according to an  $F$  distribution (Angelov & Ekström 2017, Giolo 2004, Haab & Connell 2002), as follows:

$$P(\text{WTP}_j < B_j) = F(B_j) = F_j \quad \dots(7)$$

$F_j$  is considered the cumulative rejection rate for the bid  $B_j$ , and is estimated as follows:

- Assemble bids from the smallest to the largest  $B_j$ , where  $j = 1, \dots, M$
- Calculate  $F_j$  and  $T_j$ :

$$F_j = N_j/T_j \text{ and } T_j = N_j + Y_j \quad \dots(8)$$

where  $N_j$  is the number of individuals selecting “No” and  $Y_j$  is the number of individuals selecting “Yes” at the bid  $B_j$ ;  $F_j = P(\text{WTP} \leq 0)$ .  $F_j$  is then adjusted to  $F_j^*$  as follows:

- Compare  $F_j$  with  $F_{(j+1)}$ :

If  $F_j \leq F_{(j+1)}$ , then set  $F_j^* = F_j$  and continue with  $j = j + 1$ ;

If  $F_j > F_{(j+1)}$ , then proceed to merge the two bid steps  $B_j$  and  $B_{(j+1)}$  into one group with the upper and lower bounds being  $[B_j, B_{(j+2)}]$  and computing  $F_j^*$ :

$$F_j^* = (N_j + N_{(j+1)}) / (T_j + T_{(j+1)}) \quad \dots(9)$$

- Repeat the step until a monotonically increasing series is built. The probability density of willingness to pay  $f_j^*$  from the bid  $B_j$  and  $B_{(j+1)}$  is then calculated as follows:

$$f_j^* = F_{(j+1)}^* - F_j^* \quad \dots(10)$$

- Set the last cumulative probability  $F^*(M+1)$  to 1; the mean WTP is estimated as follows:

$$\text{WTP} = \sum B_j f_{(j+1)}^* \quad \dots(11)$$

- VSL estimation

VSL is an economic metric used in cost-benefit analysis to estimate the monetary value an individual places on reducing the risk of premature death. It reflects the aggregate WTP across a population for small mortality risk reductions. Consequently, studies often show a strong correlation between VSL and income (Cropper et al. 2011, Viscusi & Aldy 2003), and a lower VSL is generally assigned to public goods than to private goods (Biausque 2012). It is therefore obtained by taking the limit of WTP or willingness to accept (WTA) when the change in risk is infinitesimal, as shown in Eq. (12).

$$\text{VSL} = \frac{w}{p(1 - \gamma)} \text{ and } \gamma \in [0,1] \quad \dots(12)$$

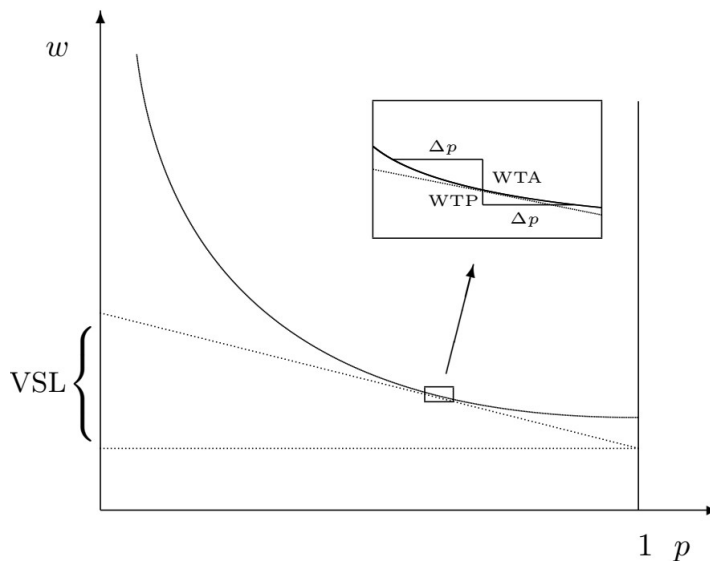


Fig. 3: Theoretical VSL value according to wealth (w) and survival probability (p).

Where  $w$  is an individual's wealth and  $p$  is the individual's survival probability over a given period. In other words, VSL is the positive slope between the change in wealth and the probability of death, illustrated in Fig. 3 (Andersson & Treich 2013, Hammitt 2000).

In practice, VSL is estimated based on the WTP as shown in Eq. (13) (Criado & Veronesi 2013, Kenkel 2003, Kniesner & Viscusi 2019).

$$VSL = \frac{WTP}{d_r} \quad \dots(13)$$

Where VSL is the statistical value of life corresponding to the risk reduction  $d_r$ ; WTP is the individual's willingness to pay, obtained using the closed-ended contingent valuation method; and  $d_r$  is the achieved risk reduction.

In this study, the risk reduction is defined as a decrease of one unit (from 48/10,000 to 47/10,000). Under this framework, with an individual risk reduction 1/10,000, the VSL per statistical life saved is calculated as eq. (14)

$$VSL = \frac{WTP}{1/10,000} = WTP \times 10,000 \quad \dots(14)$$

Additionally, multiplying the mean individual WTP by the relevant adult population of Ho Chi Minh City yields the aggregate population WTP, representing the total annual economic value generated by the risk reduction program

### 3. RESULTS AND DISCUSSION

The initial dataset was refined by excluding 128 questionnaires identified as containing either outlier responses or internal inconsistencies. Internal inconsistencies were assessed by cross-checking responses across the survey sections. Questionnaires were flagged when respondents reported low perceived risk or no air-pollution-related health impacts ( $H_1$ – $H_{18}$ ) but subsequently stated implausibly high willingness-to-pay (WTP) values. In addition, responses were excluded when participants indicated limited financial capacity in the validation questions but selected high payment bids for the proposed mitigation program.

Outliers were identified through a two-stage screening process. First, anomalous WTP responses were flagged using Excel-based filtering procedures. Second, all flagged questionnaires were manually reviewed across the full set of survey questions, including sociodemographic information, to verify and remove invalid observations. Following this quality-control process, 879 valid responses were retained for subsequent analysis.

Table 2: Chi-square statistics of H25 versus demographic variables.

| Influencing variables | Chi-square value | p-value | Contingency coefficient | Cramer's V |
|-----------------------|------------------|---------|-------------------------|------------|
| Income ( $H_1$ )      | 46.8             | < 0.001 | 0.225                   | 0.231      |
| Education ( $H_4$ )   | 49.0             | < 0.001 | 0.198                   | 0.202      |
| Age ( $H_2$ )         | 22.2             | < 0.001 | 0.157                   | 0.159      |
| Residence ( $H_5$ )   | 18.3             | 0.003   | 0.143                   | 0.144      |
| Gender ( $H_3$ )      | 2.0              | 0.161   | -                       | -          |

### 3.1. Results of the Influencing Factors

#### 3.1.1. Relationship Between Demographic Information and the Decision to Reduce Income

A chi-square test was applied to examine the relationship between demographic information ( $H_1$ – $H_5$ ) and the decision to reduce income ( $H_{25}$ ). The results showed that demographic factors, including income ( $H_1$ ), age ( $H_2$ ), educational level ( $H_4$ ), and residence ( $H_5$ ), were all found to be significantly associated with the respondents' decision (Table 2). Cramer's V and the contingency coefficient were also used to assess the strength of the associations. The analysis yielded values between 0.1 and 0.3, indicating weak associations among the variables.

- Income and Education

Among all variables analyzed, income and education emerged as the primary determinants, yielding the highest Cramer's V and contingency coefficients. The categorical divergence within these factors is illustrated in Fig. 4.

The lowest income group exhibited the strongest inclination toward "Yes" responses, with the frequency more than doubling that of "No" choices. Conversely, the 5–10 million VND group showed a sharp reversal, where "No" responses peaked at over 64%. While the mid-to-high income segments maintained a stable preference for "No", a notable shift occurred in the two highest groups (more than 20 million VND per month), the "Yes" rate regained slight dominance, converging at 55.2% for both. In addition, respondents with high school or undergraduate/college backgrounds leaned toward "Yes" (61% and 58%, respectively). In contrast, those in other categories, particularly those with postgraduate degrees, demonstrated a higher propensity for "No" responses.

- Age and Residence

Age and residence exhibited statistically significant but relatively weak associations with the decision-making outcome, with Cramer's V coefficients of 0.159 and 0.144, respectively. These patterns are illustrated in Fig. 5.

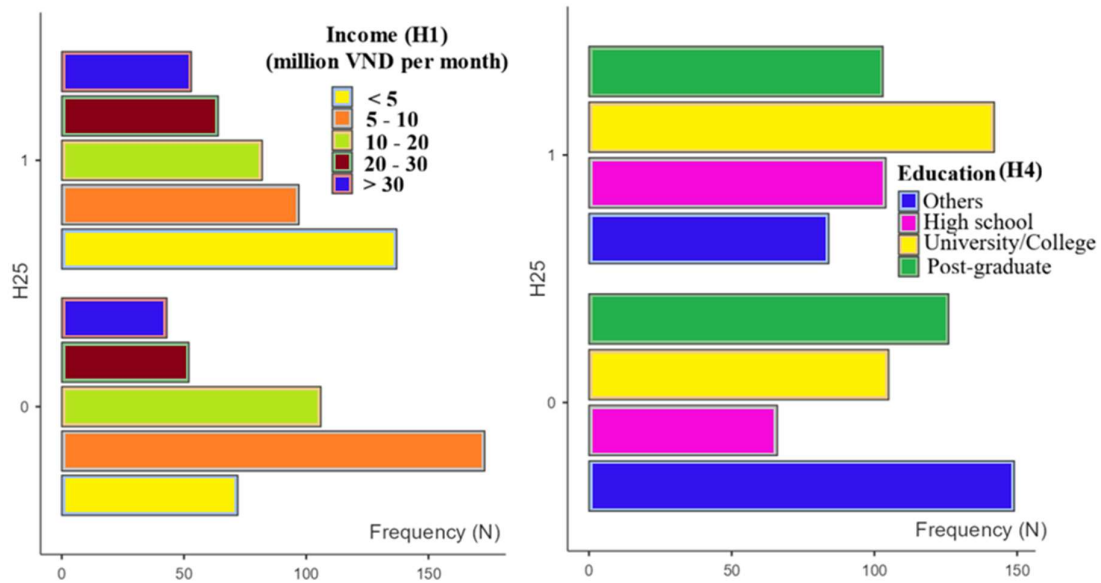


Fig. 4: Relationship of income and education to respondents' decision.

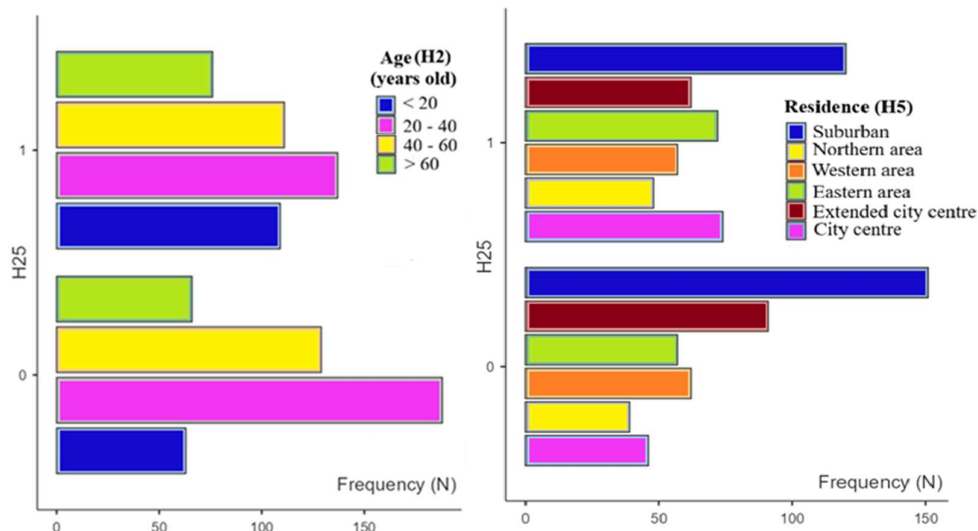


Fig. 5: Relationship of age and residence to respondents' decision.

Age-related differences were observed in respondents' choices. The highest proportion of "Yes" responses was recorded among respondents under 20 years of age (63%), whereas those aged 20–60 years showed a slight preference for "No" responses (53%–58%). Among respondents aged over 60 years, the share of "Yes" responses increased to 53.5%.

Spatial patterns were similarly modest. Respondents residing in suburban areas and the eastern and northern urban districts were somewhat more likely to select "Yes" (67.0%, 55.8%, and 55.2%, respectively), while respondents from

other areas showed a slight preference for "No". Overall, the observed differences across residential groups were relatively limited.

### 3.1.2. Possibility of Reducing Income to Improve Environmental Quality

- The binary logistic model

Binary logistic regression was employed to identify factors influencing respondents' willingness to accept a reduction in income in exchange for improved environmental quality ( $H_{25}$ ). Independent variables

Table 3: Model summary.

|                 | B      | SE    | Odds ratio | Wald statistic | p-value |
|-----------------|--------|-------|------------|----------------|---------|
| (Intercept)     | 2.936  | 0.548 | 18.832     | 33.652         | <0.001  |
| H <sub>10</sub> | 0.982  | 0.079 | 2.670      | 138.386        | <0.001  |
| H <sub>15</sub> | -1.399 | 0.122 | 0.247      | 128.559        | <0.001  |

included demographic characteristics and self-reported health-related indicators. Among the variables examined, the perceived importance of health relative to income (H<sub>10</sub>) and self-reported pneumonia-related symptoms (H<sub>15</sub>) were significantly associated with the probability of accepting reduced income for environmental improvement. The results are reported in Table 3.

Both H<sub>10</sub> and H<sub>15</sub> were statistically significant predictors of the outcome variable ( $p < 0.05$ ). The relatively small standard errors indicate stable coefficient estimates, while the large Wald statistics demonstrate the substantial contribution of these variables to the model. Compared with the intercept term, H<sub>10</sub> and H<sub>15</sub> account for a considerably greater proportion of the model's explanatory power, highlighting their importance in predicting respondents' willingness to accept income reductions for environmental improvement.

The negative coefficient associated with H<sub>15</sub> indicates an inverse relationship with the probability of a positive response to H<sub>25</sub>. Specifically, as H<sub>15</sub> increases by one point on the five-point Likert scale, the odds of a positive response to H<sub>25</sub> are multiplied by 0.247, corresponding to a reduction of approximately 75.3% in the odds. In contrast, H<sub>10</sub> (income level) exhibits a positive association with H<sub>25</sub>. A one-unit increase in H<sub>10</sub> is associated with a 2.67-fold increase in the odds of a positive response to H<sub>25</sub>, suggesting that respondents with higher income levels are more likely to provide a positive response.

From these results, the logistic probability function for a respondent's willingness to agree, conditioned on variables H<sub>10</sub> and H<sub>15</sub>, is defined by Eq. (14) as follows:

$$\ln\left(\frac{P}{1-P}\right) = 2.936 + 0.982 * H_{10} - 1.399 * H_{15} \quad \dots(14)$$

To assess the stability and robustness of the logistic regression model, multicollinearity diagnostics were conducted for the independent variables H<sub>10</sub> and H<sub>15</sub>. The

Table 4: Multicollinearity diagnostics.

|                 | Tolerance | VIF   | Correlation between H <sub>10</sub> and H <sub>15</sub> |
|-----------------|-----------|-------|---------------------------------------------------------|
| H <sub>10</sub> | 0.785     | 1.274 | -0.464                                                  |
| H <sub>15</sub> | 0.785     | 1.274 |                                                         |

results are presented in Table 4.

As shown in Table 4, both variables exhibit a variance inflation factor (VIF) of 1.274, well below the commonly accepted threshold of 5.0, while the corresponding tolerance value of 0.785 exceeds the minimum recommended level of 0.20. In addition, the correlation coefficient between the variables (-0.464) is substantially lower than the critical threshold of 0.70. Collectively, these diagnostics indicate that multicollinearity is not a concern in the present study (Hair et al. 2019).

- Model performance

The predictive capability is assessed by the parameters shown in Table 5. The model yields an area under the curve (AUC) of 0.814, signifying a high degree of discriminatory power in distinguishing between categorical outcomes. This is complemented by an F-measure of 0.722, which confirms a stable equilibrium between sensitivity and precision, ensuring that the model minimizes both Type I and Type II errors.

The reliability of predictors H<sub>10</sub> and H<sub>15</sub> is further substantiated by an accuracy of 0.741 and a precision of 0.765. Particularly, the specificity of 0.796 exceeds the sensitivity (0.684), suggesting that the model is significantly adept at identifying "disagreement" cases (H<sub>25</sub> = 0). This characteristic is vital for mitigating the risks associated with false-positive predictions in decision-making. Furthermore, the Brier score of 0.172, which is approaching the ideal value of zero, indicates that the predicted probabilities are closely aligned with empirical observations. While a numerical disparity exists between the AUC (0.814) and the H-measure (0.360), this is expected given the H-measure's more stringent treatment of cost-weighted misclassifications. Nevertheless, an H-measure of 0.360 (falling within the 0.3–0.5 range) reflects a highly satisfactory level of predictive effectiveness for behavioral modeling.

A robust approach to evaluating the model's classificatory efficiency involves the receiver operating characteristic (ROC) curve, shown in Fig. 6. The ROC curve (representing model performance) exhibits a strong trajectory toward the

Table 5: Model evaluation parameters.

| AUC   | Precision | F-measure | Brier score | H-measure |
|-------|-----------|-----------|-------------|-----------|
| 0.814 | 0.765     | 0.722     | 0.172       | 0.360     |

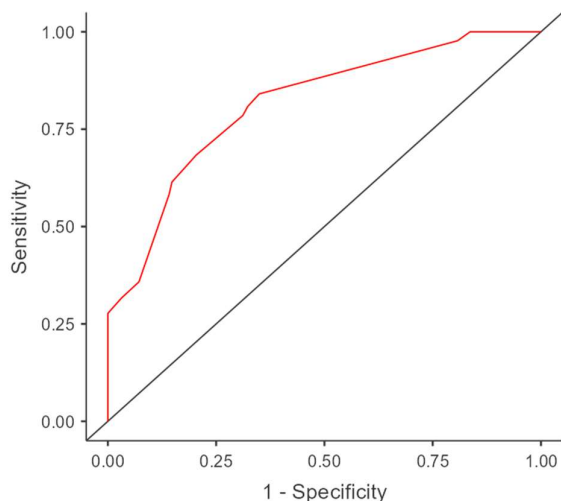


Fig. 6: Receiver operating characteristic (ROC) curve.

upper-left quadrant. This trend indicates that the model achieves high sensitivity while maintaining a low false-positive rate, confirming its robust discriminatory capability.

Regarding the assessment of model fit and diagnostic residuals, Fig. 7 presents the squared Pearson residuals plot, yielding several observations. The high concentration of data points near the baseline (zero) demonstrates that the model aligns exceptionally well with the vast majority of the empirical data. The presence of isolated observations with values exceeding 5 identifies specific outliers. These points warrant careful consideration as they may potentially attenuate the overall predictive accuracy of the model. The red trend line, which depicts the mean residual path, shows a low, smooth profile with a minimal gradient. This suggests that the error distribution remains relatively stable across all probability bands, reinforcing the model's consistency in behavioral prediction.

The Hosmer–Lemeshow test was significant ( $\chi^2 = 25.814$ ,  $df = 5$ ,  $p < 0.001$ ), suggesting some deviation between observed and predicted probabilities. However, because

Table 6: Model summary.

|       | Deviance | AIC     | BIC      | df  | $\Delta\chi^2$ | p      | McFadden $R^2$ | Nagelkerke $R^2$ | Tjur $R^2$ | Cox & Snell $R^2$ |
|-------|----------|---------|----------|-----|----------------|--------|----------------|------------------|------------|-------------------|
| $M_0$ | 1218.4   | 1220.36 | 1225.139 | 878 |                |        | 0.000          |                  | 0.000      |                   |
| $M_1$ | 894.9    | 900.94  | 915.279  | 876 | 323.42         | < .001 | 0.265          | 0.410            | 0.315      | 0.308             |

Note:  $M_0$  is the no-variable model;  $M_1$  includes H10 and H15.

Table 7: Classification matrix for the binary logistic model.

|                    |       | Predicted observation |     | % Correct |
|--------------------|-------|-----------------------|-----|-----------|
|                    |       | 0                     | 1   |           |
| Actual observation | 0     | 355                   | 91  | 79.6      |
|                    | 1     | 137                   | 296 | 68.4      |
|                    | Total | 492                   | 387 | 74.1      |

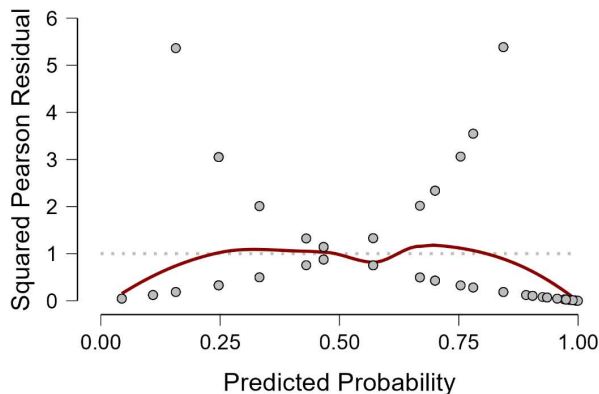


Fig. 7: Squared Pearson residuals plot.

this test is highly sensitive to large sample sizes ( $N = 879$ ) and may overreject well-fitting models (Hosmer et al. 2013, Paul et al. 2013), model fit was evaluated primarily using pseudo- $R^2$  statistics and predictive validation metrics (Table 6).

The model showed good explanatory performance, with a Nagelkerke  $R^2$  of 0.410 and a McFadden  $R^2$  of 0.265, values generally considered indicative of a satisfactory fit in discrete choice models (Hosmer et al. 2013, McFadden 1977). Furthermore, model deviance decreased from 1218.4 for the null model to 894.9 for the fitted model, corresponding to a highly significant likelihood-ratio test ( $\Delta\chi^2 = 323.418$ ,  $p < 0.001$ ). These findings indicate that the proposed model substantially improves upon the null specification and captures a meaningful proportion of the variation in the response variable.

- Model predictive performance

The predictive performance of the binary logistic regression model was assessed using a classification matrix. The corresponding results are reported in Table 7.

The model correctly predicted 651 cases out of a total of 879 observations, yielding an overall accuracy of 74.1%. For “No” responses (Value 0), the model correctly predicted 355

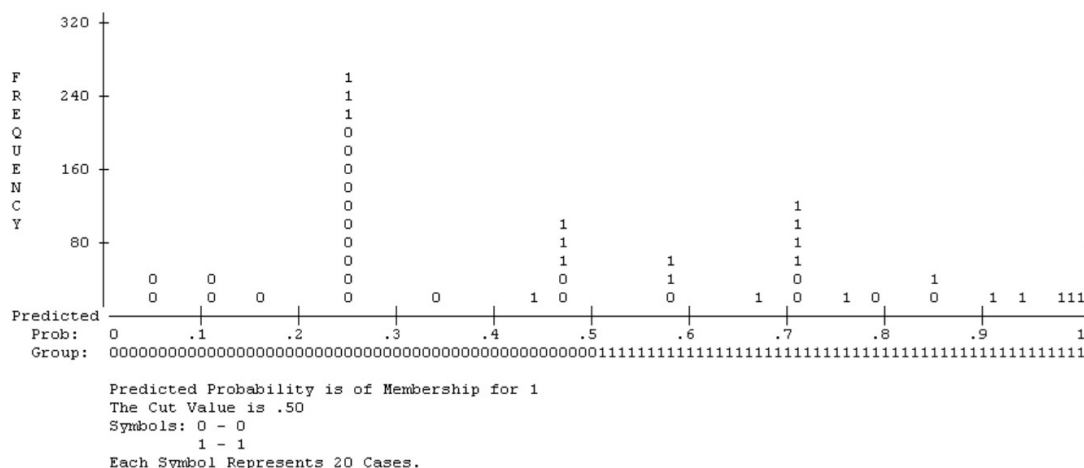


Fig. 8: Observed and predicted probability distribution.

cases out of 446 actual observations, achieving a specificity (true negative rate) of 79.6%. For “Yes” responses (Value 1), the model correctly predicted 296 cases out of 433 actual observations, achieving a sensitivity (true positive rate) of about 68.4%.

The distributions of the dependent variable H25 for the actual and predicted values from the model are shown in Fig. 8. For value 0, the actual and predicted values are similarly concentrated in the left portion of the graph, consistent with a prediction accuracy above 79%. For value 1, the model also performs reasonably well, with most observed and predicted values concentrated in the right portion of the graph and a prediction accuracy above 68%.

#### • Model validation

To evaluate the predictive performance and generalizability of the logistic regression model, the dataset

Table 8: Cross-validation test results.

|                                       | 0     | 1     | Average/<br>Total |
|---------------------------------------|-------|-------|-------------------|
| Precision (positive predictive value) | 0.712 | 0.812 | 0.764             |
| Recall (true positive rate)           | 0.825 | 0.693 | 0.757             |
| False positive rate                   | 0.307 | 0.175 | 0.241             |
| False discovery rate                  | 0.288 | 0.188 | 0.238             |
| F1 score                              | 0.765 | 0.748 | 0.756             |
| Matthews correlation coefficient      | 0.522 | 0.522 | 0.522             |
| Area under curve (AUC)                | 0.759 | 0.759 | 0.759             |
| Negative predictive value             | 0.812 | 0.712 | 0.762             |
| True negative rate                    | 0.693 | 0.825 | 0.759             |
| False negative rate                   | 0.175 | 0.307 | 0.241             |
| False omission rate                   | 0.188 | 0.288 | 0.238             |

(N = 879) was randomly partitioned into training (70%; n = 616) and testing (30%; n = 263) subsets. The model was developed using the training data and subsequently evaluated on the independent test set. All analyses were conducted in JASP, and the validation results are reported in Table 8.

The model exhibited satisfactory predictive performance on the independent test set, with an accuracy of 0.757, an F1 score of 0.756, and an AUC of 0.759. The modest decline in AUC relative to the full-sample estimate (0.814) indicates that the model generalizes well to unseen data and is not substantially affected by overfitting.

The corresponding ROC curves are illustrated in Fig. 9.

Figure 9 shows that the ROC curves for both classes remain substantially above the random-classification reference line and trend toward the upper-left corner of the plot. This pattern indicates satisfactory classification

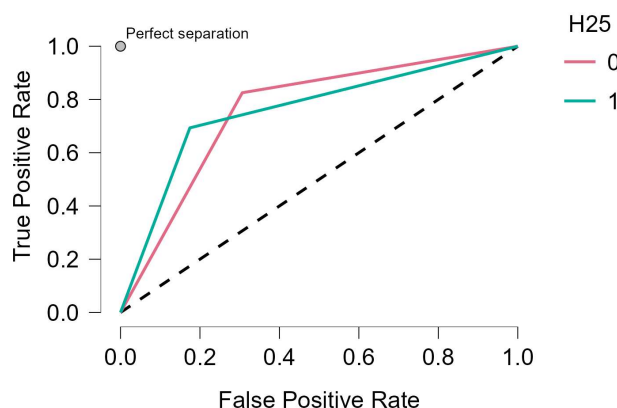


Fig. 9: Receiver operating characteristic (ROC) curves for the cross-validation test.

performance and provides additional evidence of the model's robustness and generalizability.

### 3.2. WTP and VSL Results

The study was designed to estimate the WTP for a one-unit reduction in the risk of death (from 48 to 47 deaths per 10,000 people). In the survey, respondents demonstrated a clear division when comparing personal health and income: 38% prioritized health, 20% prioritized income, and 42% considered them equally vital. However, this willingness to prioritize health did not translate into economic sacrifice. When faced with reducing income for better environmental quality, more than 70% declined, overwhelmingly citing insufficient income as the primary barrier.

The Turnbull lower-bound estimate of WTP is 17.9 thousand VND per person, as shown in Table 9. Based on Equation (14), the individual VSL for a 1/10,000 risk reduction is estimated at 179.2 million VND per statistical life saved (approximately USD 6,920 at the current exchange rate). Furthermore, aggregating the mean individual WTP across the adult target population of approximately 9.5 million people (Ho Chi Minh City's Department of Health 2025) yields an aggregate population WTP (total economic benefit) of 170.2 billion VND (approximately USD 6.57 million).

VSL is frequently estimated using a simple rule of thumb of approximately 70 times GDP per capita, representing a theoretical benchmark of an individual's lifetime economic contribution over a 70-year span (Woolley et al. 2015, World Bank 2021). According to local authorities, the GRDP per capita for Ho Chi Minh City in 2024 was approximately USD 7,600, yielding a benchmark VSL of USD 532,000 per statistical life.

In contrast, our empirical individual VSL derived from the Turnbull lower-bound estimator is 179.24 million VND (approximately USD 6,920), which is significantly lower than the theoretical GDP-based benchmark. This substantial gap is primarily explained by severe budget constraints, as

over 70% of respondents reported insufficient income to make financial sacrifices for environmental improvements. Furthermore, when evaluating the total societal impact, the aggregate population WTP across the city reaches 170.2 billion VND (USD 6.57 million), illustrating that while individual payment willingness is constrained by immediate income limits, the collective willingness to pay reflects a substantial community valuation for air quality improvement.

In comparison, our empirical individual VSL estimated via the Turnbull lower-bound method is substantially lower than the USD 1.6 million estimated by Trung & Tri (2022). This pronounced divergence stems primarily from the fundamental differences in methodology and primary data reliance. While Trung & Tri (2022) derived their VSL through a benefit transfer approach based on Taiwan's baseline values and adjusted for income, our study relies on direct, primary CVM survey data collected from local residents in Ho Chi Minh City. Direct stated-preference surveys in developing contexts frequently reflect acute, immediate budget constraints and a low willingness to make financial sacrifices—as evidenced by the 70% refusal rate in our sample—leading to lower empirical VSL values compared to transferred estimates from higher-income economies. Nevertheless, when aggregated across the city's adult population, the collective willingness to pay reaches USD 6.57 million, demonstrating that while individual capacity to pay is severely restricted, air quality improvement holds a substantial aggregate economic value for the broader community.

## 4. CONCLUSIONS

The results of this study indicate a mean individual WTP of 17,900 VND per person to achieve a 1/10,000 reduction in the air pollution-related mortality rate (from 48/10,000 to 47/10,000). Based on standard VSL formulations, this yields an individual VSL of 179.24 million VND (approximately USD 6,920) per statistical life saved. Furthermore, aggregating this individual willingness to pay across the city's adult

Table 9: WTP results according to the Turnbull lower-bound estimation.

| $B_j$<br>(USD)      | $B_j$<br>(1,000 VND) | $N_j$ | $F_j$ | $F_j^*$ | $f_j^*$ | WTP <sub>j</sub><br>(1,000 VND) |
|---------------------|----------------------|-------|-------|---------|---------|---------------------------------|
| 0                   | 0                    | 638   | 0.726 | 0.726   | 0.076   | 0.000                           |
| 0.43                | 10                   | 705   | 0.802 | 0.802   | 0.077   | 0.774                           |
| 1.52                | 35                   | 773   | 0.879 | 0.879   | 0.051   | 1.792                           |
| 4.35                | 100                  | 818   | 0.931 | 0.931   | 0.027   | 2.730                           |
| 13.04               | 300                  | 842   | 0.958 | 0.958   | 0.042   | 12.628                          |
| 21.00               | 500                  | 879   | 1.000 | 1.000   | 0.000   | 0.000                           |
| Total estimated WTP |                      |       |       |         |         | 17.924                          |

population results in an aggregate population WTP of 170.2 billion VND (equivalent to USD 6.57 million), representing the overall societal economic benefit of the proposed risk reduction program. A significant finding is the severe constraint imposed by income: more than 70% (638/879) of total respondents were unwilling to pay, overwhelmingly citing insufficient income as the primary barrier. This financial constraint is further evidenced by the fact that the group with a monthly income under 20 million VND exhibited the highest refusal rate among all income groups.

The results of this study indicate that the residents of Ho Chi Minh City (HCMC) are highly aware of the harmful effects of air pollution on their health. However, when connecting this awareness to their income, less than 30% of the surveyed individuals agreed to reduce their income (agreed to pay). Moreover, socioeconomic factors, including income, age, education level, and residence, were found to be related to the respondents' WTP decision, though these linkages are relatively weak. The segmentation analysis of the agreeing group revealed that respondents with low-to-medium incomes, young adults, those with a university education, and residents in the city center or suburban areas constituted the largest share of agreement.

The probabilistic model of the factors influencing the decision to reduce income (or agree to pay) simultaneously revealed that respondents' assessments of health symptoms played an important role in prediction. The probabilistic model also demonstrated reasonably good predictive values, with an overall correct prediction rate above 74% and an AUC of about 0.81.

The segmentation analysis of the agreeing group revealed that respondents with low-to-medium incomes, young adults, those with a university education, and residents in the city center or suburban areas constituted the largest share of agreement.

The results of this study indicate that the residents of Ho Chi Minh City (HCMC) are highly aware of the harmful effects of air pollution on their health. However, when connecting this awareness to their income, less than 30% of the surveyed individuals agreed to reduce their income (agreed to pay). Looking specifically at the demographic composition of the agreeing group, the majority of respondents were young adults (20–40 years old) with medium-to-low incomes residing in central and suburban expansion districts."

Therefore, further specialized research focusing on the remaining demographic groups is proposed to identify underlying causes. This information can then be used to develop appropriate and effective communication and outreach strategies.

## 5. ACKNOWLEDGEMENT

The authors thank Sai Gon University, Ho Chi Minh City, Vietnam, for its support and funding.

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