# Health and Economic Effects of Air Pollution in Vietnam

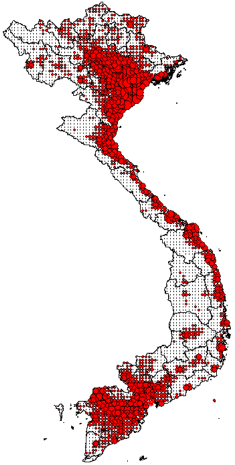
Le Viet Phu
Fulbright Economics Teaching Program

January 19, 2017

# Summary and Key Findings

- Ambient air pollution (AAP) is a major cause of death worldwide (5.5 millions in 2013).
- Conservative estimates show that more than **40,000 deaths** are attributable to PM2.5 pollution in Vietnam in 2013, about three-to-four times the number of traffic deaths. In HCMC, the number is over **3,000**. These are bottom-up epidemiological estimates using established disease incidence rates worldwide.
- The trend of AAP deaths has doubled since 1990.
- Private economic cost is significant, from **5-7 percent GDP** in 2013 based on VSL. A lower value of **0.9-1.4% GDP** is calculated based on forgone outputs.
- Immediate policy actions to reduce exposure and reduce AAP are required. Alternative scenarios show large health benefits from meeting more stringent air quality standards. One quarter of the current deaths could be reduced with the current PM2.5 requirement if properly enforced.

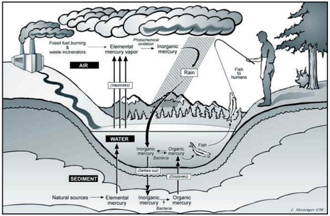
# Summary and Key Findings



- Pollution and deaths occurred primarily in the Red River Delta, HCMC and surrounding provinces in the Mekong River Delta.
- The current AA quality standard adopted by the GoV is low, however recommendation for more stringent standard is not as important as enforcement of the existing one.
- Incorporating health cost to the environmental benefit of public infrastructure projects such as urban transits.
- The hidden cost of AAP in producing cheap energy (coal) is significant. Diversification and incentives to move to clean energy is warranted.
- Much more work is needed to improve the models, the data, and assumptions.

# Table of contents

# Environmental Impact Pathway of Pollution




- Groundwater
- Terrestrial ecosystems
- Underwater ecosystems
- Air pollutions (**PM2.5**, PM10, SPM, O3, NOx, SOx)

- Climate change
- Landscape
- Noise
- Social and livelihood risks
- Cultural heritages
- Transport
- Land use
- Infrastructure
- Tourism
- Agriculture

# Typical Damages Considered in an Environmental Impact Assessment

**External costs of energy and transport: Impact pathways of health and environmental effects included in the analysis**

| Impact Category | Pollutant / Burden | Effects |
|---|---|---|
| Human Health – mortality | $PM_{10}$ [a], $SO_2$ <br> $NOx$, $O_3$ | Reduction in life expectancy |
| | Benzene, Benzo-[a]-pyrene 1,3-butadiene Diesel particles | Cancers |
| | Noise | Loss of amenity, impact on health |
| | Accident risk | Fatality risk from traffic and workplace accidents |
| Human Health – morbidity | $PM_{10}$, $O_3$, $SO_2$ | Respiratory hospital admissions |
| | $PM_{10}$, $O_3$ | Restricted activity days |
| | $PM_{10}$, CO | Congestive heart failure |
| | Benzene, Benzo-[a]-pyrene 1,3-butadiene Diesel particles | Cancer risk (non-fatal) |
| | $PM_{10}$ | Cerebro-vascular hospital admissions <br> Cases of chronic bronchitis <br> Cases of chronic cough in children <br> Cough in asthmatics <br> Lower respiratory symptoms |
| | $O_3$ | Asthma attacks <br> Symptom days |
| | Noise | Myocardial infarction <br> Angina pectoris <br> Hypertension <br> Sleep disturbance |
| | Accident risk | Risk of injuries from traffic and workplace accidents |
| Building Material | $SO_2$ <br> Acid deposition | Ageing of galvanised steel, limestone, mortar, sand-stone, paint, rendering, and zinc for utilitarian buildings |
| | Combustion particles | Soiling of buildings |
| Crops | $NO_x$, $SO_2$ | Yield change for wheat, barley, rye, oats, potato, sugar beet |
| | $O_3$ | Yield change for wheat, barley, rye, oats, potato, rice, tobacco, sunflower seed |
| | Acid deposition | Increased need for liming |
| Global Warming | $CO_2$, $CH_4$, $N_2O$, N, S | World-wide effects on mortality, morbidity, coastal impacts, agriculture, energy demand, and economic impacts due to temperature change and sea level rise |
| Amenity losses | Noise | Amenity losses due to noise exposure |
| Ecosystems | Acid deposition, nitrogen deposition | Acidity and eutrophication (avoidance costs for reducing areas where critical loads are exceeded) |

[a] *particles with an aerodynamic diameter $< 10\ \mu m$, including secondary particles (sulphate and nitrate aerosols)*

- Health impacts and deaths are part of the total damage from a standard EIA.
- Deaths and assigned economic values are the largest component of total health cost.
- This study estimates deaths as the endpoint of five diseases including Chronic Obstructive Pulmonary Disease (COPD), Lung Cancer (LNC), Lower Respiratory Infection (LRI), Ischemic Heart Disease (IHD), and Stroke (STR).

# Ambient Air Pollution and Associated Health Impacts

**$SO_2$:** Là sản phẩm của quá trình đốt các nhiên liệu như than, dầu... Đây cũng là chất góp phần gây lắng đọng axit. Thời gian tồn tại trong môi trường từ 20 phút đến 7 ngày.

**CO:** Phát tán vào môi trường do quá trình đốt không hoàn toàn các nhiên liệu hữu cơ như than, dầu, gỗ củi... Thời gian lưu trong khí quyển có thể dao động từ 1 tháng đến 2,7 năm.

**$NO_x$:** Là hỗn hợp của khí $NO_2$ và NO có mặt đồng thời trong môi trường, phát tán do quá trình đốt nhiên liệu ở nhiệt độ cao từ hoạt động giao thông, nhà máy nhiệt điện, lò hơi công nghiệp... Đây cũng là một trong những nhân tố gây ra lắng đọng axit, thường có thời gian tồn tại từ 3 – 5 ngày trong khí quyển.

**$O_3$**: Có hai loại khí ozôn, trong đó khí ozôn tầng bình lưu là loại khí giúp bảo vệ bầu khí quyển; ngược lại, ozôn tầng mặt (tầng đối lưu) là loại khí ô nhiễm thứ sinh, được hình thành từ phản ứng quang hóa giữa các hợp chất $NO_x$, VOCs, các hydrocarbon trong không khí. Thời gian tồn tại trong môi trường từ 2 giờ - 3 ngày.

**Bụi:** Bụi là tên chung cho các hạt chất rắn và hạt lỏng có đường kính nhỏ cỡ vài micrômét đến nửa milimét, tự lắng xuống theo trọng lượng của chúng nhưng vẫn có thể lơ lửng trong không khí một thời gian. Bụi đề cập trong Chương này gồm các loại bụi sau:

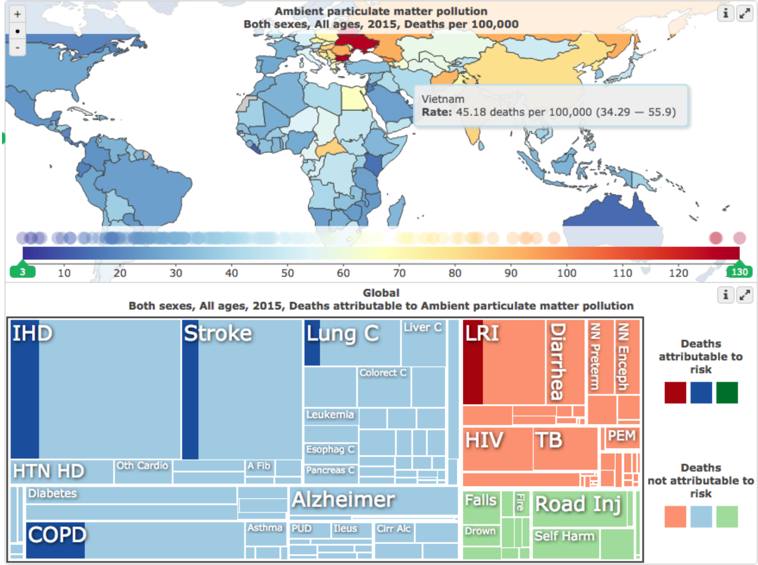
- Bụi lơ lửng tổng số (TSP): là các hạt bụi có đường kính động học ≤100µm
- Bụi $PM_{10}$: là các hạt bụi có đường kính động học ≤10µm
- Bụi $PM_{2,5}$: là các hạt bụi có đường kính động học ≤2,5µm
- Bụi $PM_1$: là các hạt bụi có đường kính động học ≤1µm

Trong các loại bụi này thì bụi $PM_{2.5}$ có khả năng đi sâu vào các phế nang phổi, gây ảnh hưởng trực tiếp đến hệ hô hấp hơn cả.

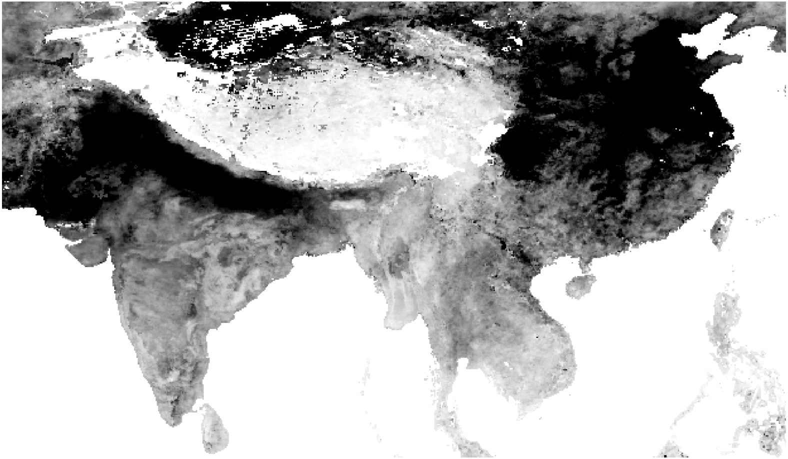
**Pb**: Có mặt trong thành phần khói xả từ động cơ của các phương tiện giao thông (trường hợp nhiên liệu có pha chì). Ngoài ra có thể phát tán từ các mỏ quặng và các nhà máy sản xuất pin, hóa chất, sơn... Thời gian lưu trong khí quyển thường dao động từ 7,5 đến 11,5 ngày.

*Nguồn: TCMT tổng hợp, 2013*

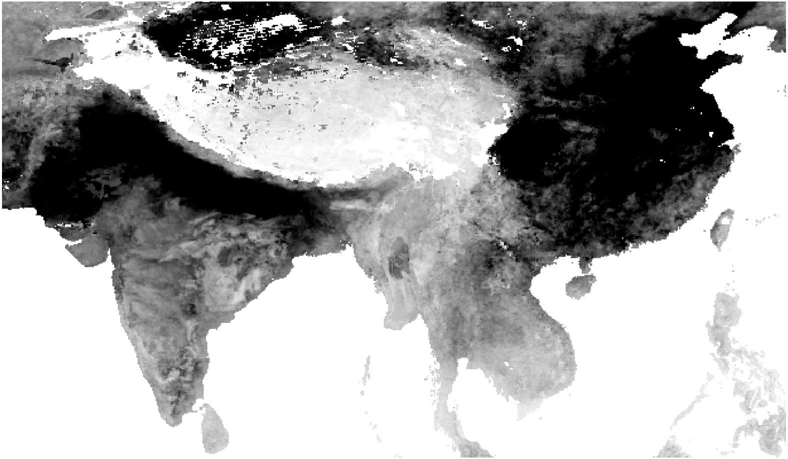
# Association between Ambient Air Pollution and Incidence of Diseases



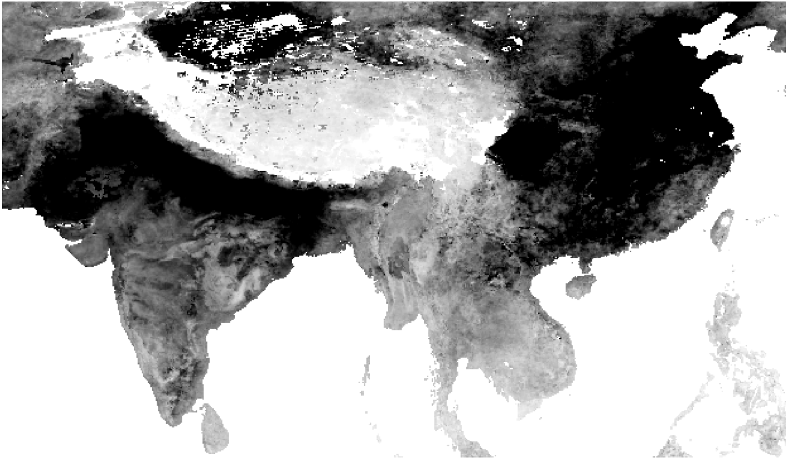
# PM2.5 Concentration in 2000



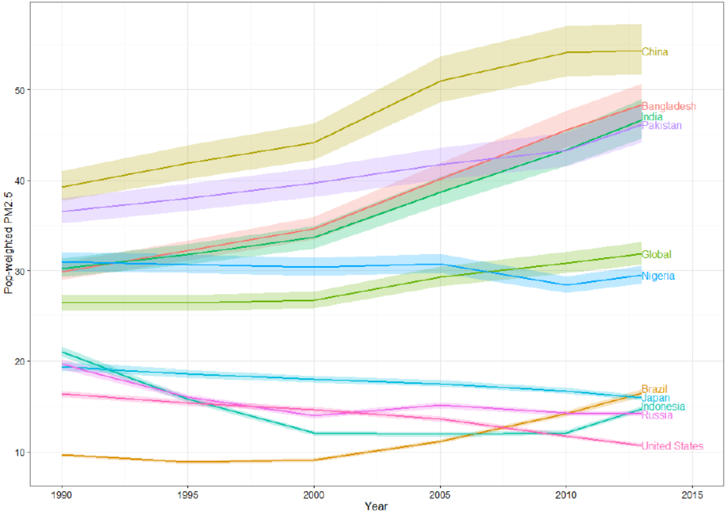
# PM2.5 Concentration in 2005



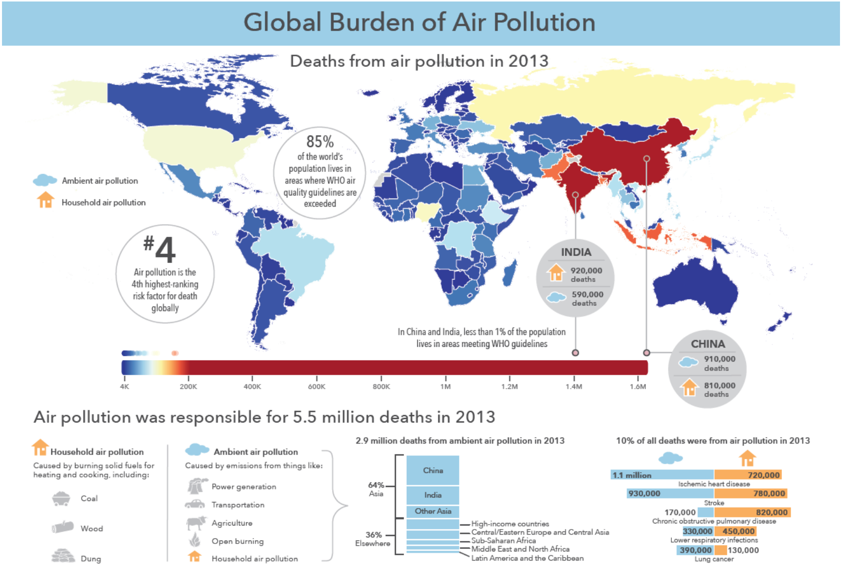
# PM2.5 Concentration in 2010



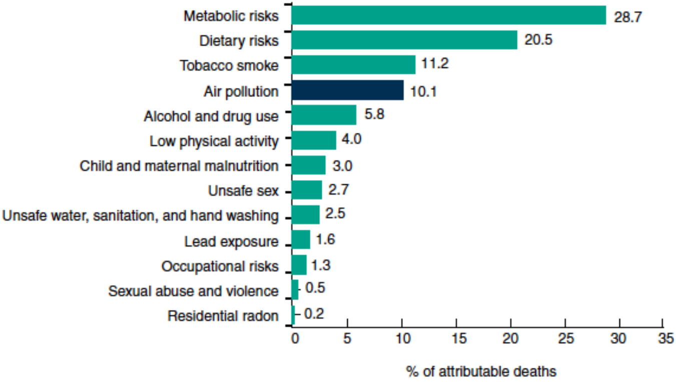
# Worldwide PM2.5 Concentration Trend (population weighted, WB 2016)



# Global Burden of Disease (World Bank 2016)



# Percentage of Attributable Deaths by Risk Factor

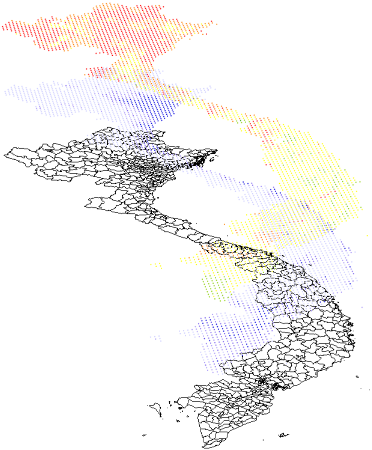



Source: Institute for Health Metrics and Evaluation

# Data Sources

- Global Burden of Disease (GBD)'s remote sensing data of PM2.5 at a 0.1x0.1 degree resolution (approximately 10km in Vietnam). This data has been validated by ground monitoring data to provide a consistent global coverage.
- Population at each grid of the GBD data.
- Relative risk table produced by Apte et al (2016) for five mortality related diseases.
- Value of Statistical Life, and forgone outputs derived from World Bank reports.

# Data Structure



- 10x10km (approx.) gridded concentration of annual average PM2.5 from 1990 to 2013 covering Vietnam.
- Population count in each grid.
- Relative risk to PM2.5 concentration levels derived by Apte et al (2015) for the five diseases with mortality endpoint including COPD, LNC, LRI, IHD, and STR.

# Air Pollution in Vietnam

**Bảng 3.1. Giá trị giới hạn các thông số cơ bản trong môi trường không khí xung quanh theo QCVN 05:2013/BTNMT – Quy chuẩn kỹ thuật quốc gia về chất lượng không khí xung quanh**

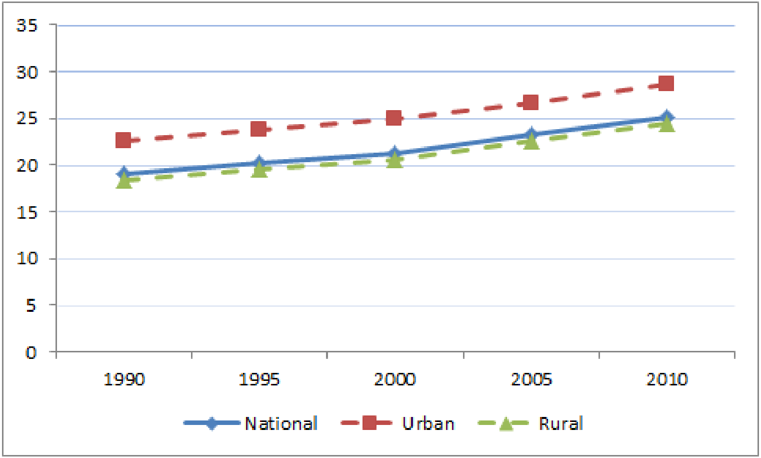
*Đơn vị: µg/m³*

| Thông số | Trung bình 1 giờ | Trung bình 8 giờ | Trung bình 24 giờ | Trung bình năm |
|---|---|---|---|---|
| $SO_2$ | 350 | - | 125 | 50 |
| CO | 30.000 | 10.000 | - | - |
| $NO_2$ | 200 | - | 100 | 40 |
| $O_3$ | 200 | 120 | - | - |
| Bụi lơ lửng (TSP) | 300 | - | 200 | 100 |
| Bụi $PM_{10}$ | - | - | 150 | 50 |
| Bụi $PM_{2,5}$ | - | - | 50 | 25 |
| Pb | - | - | 1,5 | 0,5 |

*Chú thích: ( - ) Không quy định*

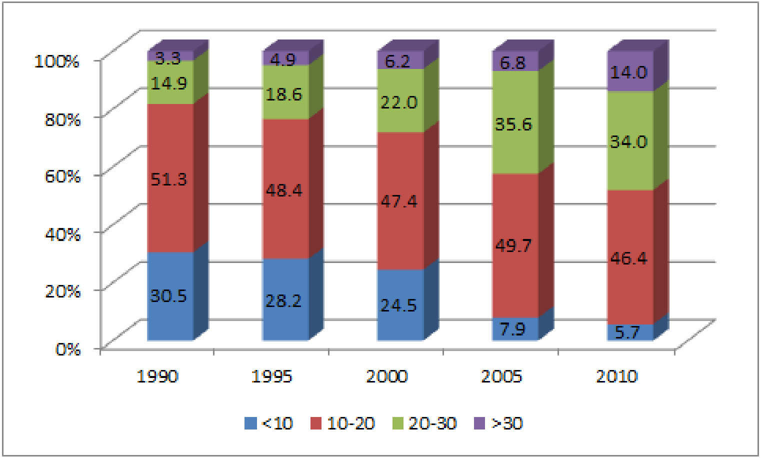
- PM2.5 concentration increases in almost all locations
- Urban areas are subject to a greater increase in absolute value.
- More people are exposed to AAP due to migration and increasing concentration in small areas.

# Vietnam PM2.5 Concentration Trend (population weighted)

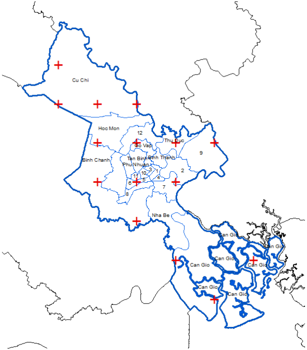


# PM2.5 Concentration Distribution in Vietnam

as a per cent of the land area:



# HCMC Data Grids, Location Designations, and Monitoring Data



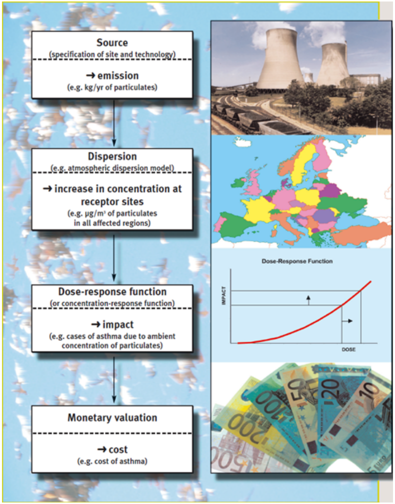

| Location | pm1990 | pm1995 | pm2000 | pm2005 | pm2010 | pm2011 | pm2012 | pm2013 |
|---|---|---|---|---|---|---|---|---|
| Can Gio | 8.7 | 9.9 | 10.9 | 10.8 | 11.8 | 11.9 | 12 | 12.2 |
| Can Gio | 9.8 | 10.8 | 12 | 13.7 | 14.9 | 15.2 | 15.4 | 15.6 |
| Can Gio | 9.6 | 10.2 | 10.8 | 11.2 | 13.1 | 12.4 | 11.7 | 11.1 |
| Binh Chanh-Nha Be | 15 | 16 | 17 | 18.4 | 20 | 20.2 | 20.4 | 20.6 |
| Binh Chanh-Binh Tan | 18.9 | 20 | 21 | 22.3 | 22.6 | 22.8 | 23 | 23.2 |
| 1-2-3-5-6-8-11 | 19 | 19.4 | 20 | 21.5 | 22.7 | 23.7 | 24.6 | 25.7 |
| 2-7 | 15.5 | 15.9 | 16.5 | 17.8 | 19.3 | 19.8 | 20.3 | 20.7 |
| Hoc Mon-Binh Chanh | 20 | 21.2 | 22.3 | 23.1 | 23.9 | 23.6 | 23.4 | 23.1 |
| Go Vap-12 | 24 | 24.5 | 25.3 | 26.1 | 27.1 | 27.4 | 27.6 | 27.9 |
| Thu Duc | 18.3 | 18.9 | 19.7 | 21.1 | 23.3 | 23.5 | 23.7 | 24 |
| 9 | 16.1 | 16.6 | 17.4 | 18.4 | 20.9 | 20.9 | 20.9 | 20.9 |
| Cu Chi/Tan An Hoi | 17 | 18.2 | 19.6 | 23.4 | 23.4 | 23.9 | 24.3 | 24.7 |
| Cu Chi/Tan Phu Trung | 20.7 | 22 | 23.3 | 25.5 | 26 | 26.3 | 26.5 | 26.8 |
| Cu Chi/Binh My | 22.1 | 23.6 | 25 | 26.7 | 28.1 | 28.3 | 28.6 | 28.9 |
| Cu Chi/Trung Lap Thuong | 15.8 | 16.3 | 17.2 | 20.8 | 22.7 | 22.5 | 22.3 | 22.1 |

# Methods used in Estimating Health Impacts and Economic Valuation

- Direct measurement (epidemiology): good to understand the mechanism of impact in a case-control situation.

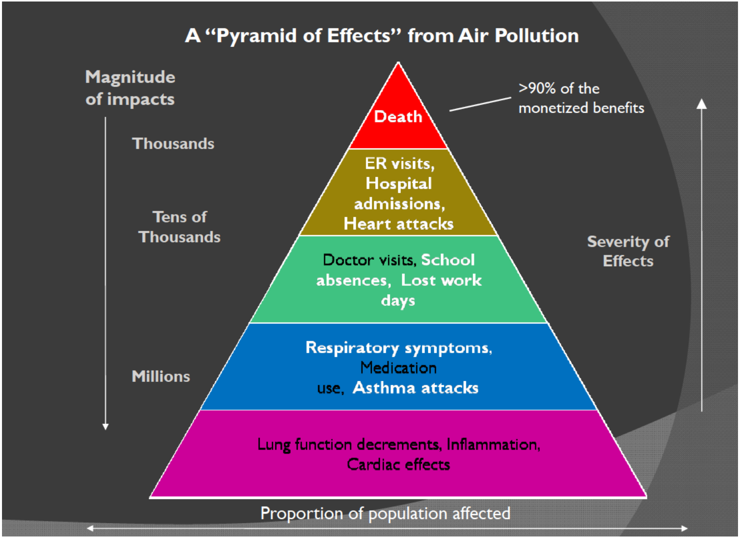
- Indirect measurements (mostly economics): randomization, natural experiments, WTP, travel cost method (TCM), defensive behavior, hedonic valuation of real estates, benefit transfer (meta-analysis). Often difficult to establish causality.

# Impact Pathway Approach Method




- Emissions
- Dispersions and exposure
- Dose-response function and health impact
- Monetization of damages

# Exposure, Disease Incidence, and Mortality Pyramid



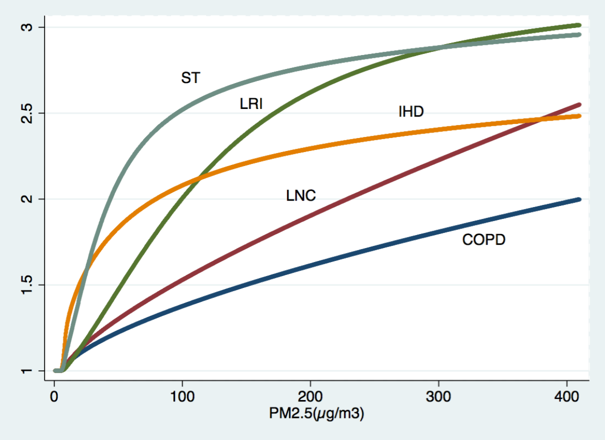
# Exposure - Risk Function

- Used to connect from exposure to incidence of disease via the Relative Risk coefficient, $RR = \frac{P_{success}}{1-P success}$, measured at the concentration the person is exposed to:

$$RR(C) = 1 + \alpha[1 - e^{-\gamma(C-C_0)^{\sigma}}] \text{ for } C \geq C_0$$
$$RR = 1 \text{ for } C < C_0$$

- $C_0$ is the minimum concentration above which there is a risk to health due to exposure. The theoretical limit is between 5-8 $\mu$g $m^{-3}$.
- $RR = 1$ happens when exposure does not change the incidence of disease.

# Relative Risk Estimates based on Epidemiological Studies




RR is numerically derived so there is no functional form! RR is provided at each level of PM2.5 exposure up to 410 $\mu g/m^{-3}$.

# From Risk to Health Impact Function

To link exposure to health impacts (number of deaths):

$$H = \frac{RR-1}{RR} \times B \times POP$$

- $\frac{RR-1}{RR}$ is the attributable fraction (AF) due to increased risk to exposure.
- B is the baseline incidence. $RR > 1 \rightarrow$ increases health impact above the baseline due to exposure.
- POP is the total population exposed to risk.
- This study did not decompose exposed population by age due to lack of data.

# Economic Valuation of Health Impact

- Welfare-based approach: monetize increased risks of death from air pollution based on the Willingness to Pay (WTP).
  - Measure the full cost of premature deaths, including leisure, consumption, good health.
  - Neither the value of any specific person's life, nor a social judgment of what it should be.
- Income-based approach: measure forgone lifetime earnings due to premature deaths.
  - Make more sense from a standpoint of a nation as a whole, as death is disinvestment in human capital.
- Both has advantages and disadvantages.

# Willingness to Pay Approach: the Value of Statistical Life

- Often used in developed countries. The VSL estimated in the US is about US$5-10m. The World Bank use US$3.83m.
- Difficult to estimate in developing countries. Must use a benefit transfer approach to infer the value.
- VSL is highly influenced by income.

$$VSL_{VNM} = VSL_{OECD} \times \left[ \frac{Y_{VNM}}{Y_{OECD}} \right]^{\gamma}$$

  $\gamma$ is the elasticity of VSL to income. The World Bank recommends to use 1.2 for low- and middle-income countries.
- Calculated VSL in Vietnam range from a low value of US$241,128 to a high value of US$304,583.

# Forgone Earnings due to Premature Deaths

- Assume that death occurs at 30, 40, and 50 years old on average, and the average life expectancy (remain working) is 70, then the number of years of lost earnings is 40, 30, and 20 years.
- The present value of lost earnings for T years is calculated as:

$$PV = Y_0 \times \sum_{j=1}^{T} \frac{(1+g)^j}{(1+r)^j}$$

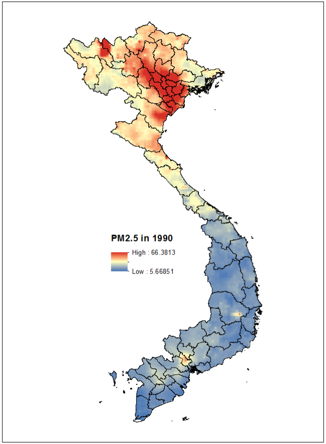
with $Y_0$ is the annual average earning per person in the labor force. $g$ and $r$ are the income growth rate, and discount rate.

- g=3% and r=6% as per a WB recommendation.
- $Y_{2013} = \frac{GDP_{2013}}{POP \times pRate} = \frac{171*10^9}{89.71*10^6*.777} = US\$2,453.$

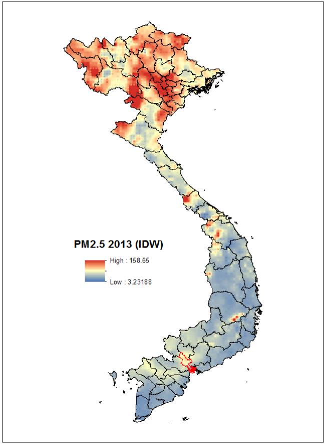
# Results

PM2.5 concentration in 1990 vs 2013

1990

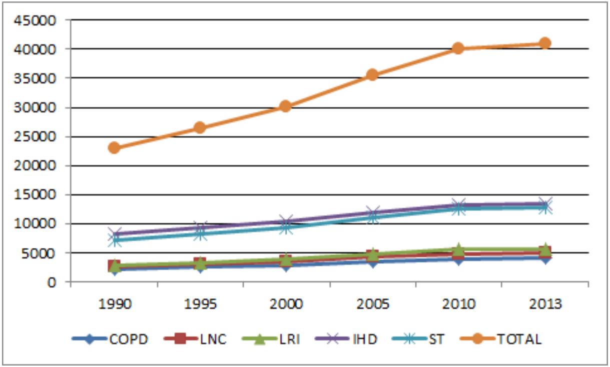



2013



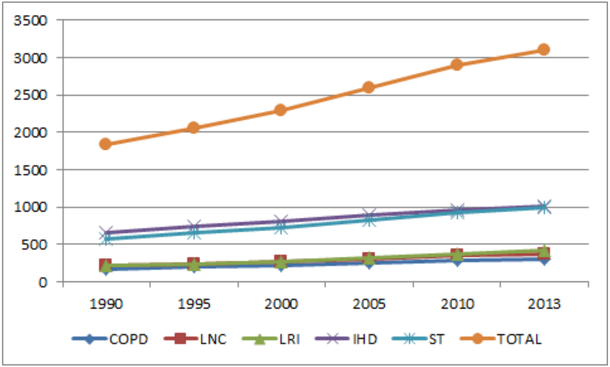
# Death-by-Cause Trend

Deaths by causes in Vietnam due to AAP



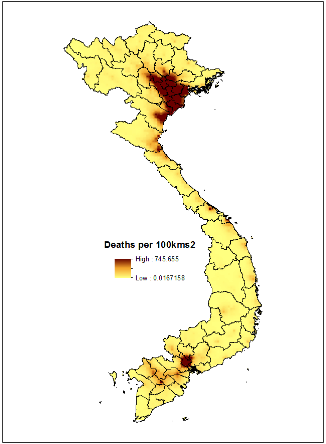
# Death-by-Cause Trend

Deaths by causes in HCMC due to AAP

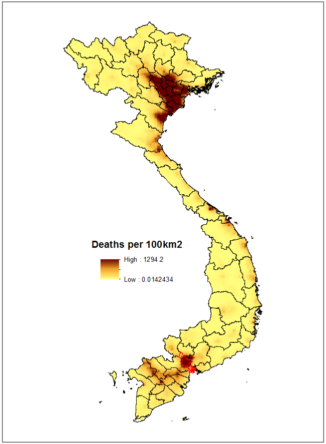


# Number of Deaths in 1990 vs 2013

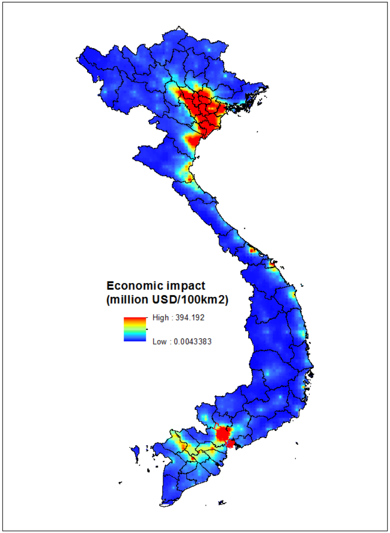
1990




2013

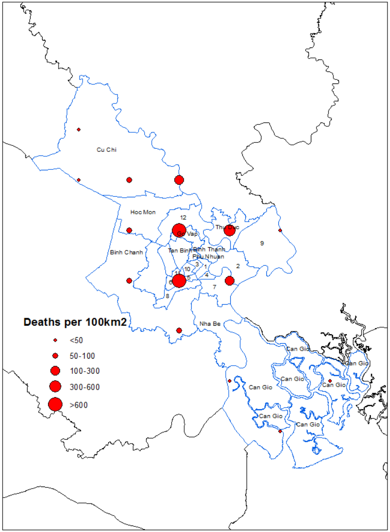


# Economic Cost from Premature Deaths in Vietnam in 2013




- Cost is US$9.86bn and US$12.45bn in 2013 based on the WTP approach, using low and high VSL estimates, equivalent to 5.77 and 7.28% of GDP in 2013.
- Based on forgone output, the loss is US$1.55, US$2.05, and US$2.42bn, respectively. In GDP range: 0.9 to 1.42%.

# Estimates of Deaths and Economic Cost in Ho Chi Minh City in 2013




- US$.75-.94bn (2.06-2.6% of HCMC 2013 GDP of US$36.2bn) based on WTP.
- US$117-183m (0.32-0.51% of HCMC 2013 GDP of US$36.2bn) based on forgone earnings.

# Comparison with Health Impact and Economic Cost in Other Regions (World Bank report, 2016)

**FIGURE 3.1 Welfare Losses Due to Air Pollution by Region, 2013**

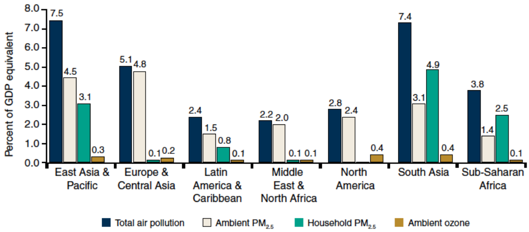
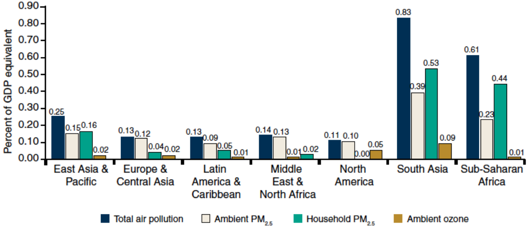



**FIGURE 3.2 Forgone Labor Output Due to Air Pollution by Region, 2013**



# Health and Economic Benefit from Air Quality Attainments to Alternative Standards

- Scenario 1: all locations exceeding the current national PM2.5 standard ($25\mu g/m^{-3}$ per year) will meet the standard.
  Total deaths = 32,465 (COPD 3,437 LNC 4,195 LRI 4,334 IHD 12,645 ST 7,854), down from 40,882 in 2013.
- Scenario 2: Lowering the national standard to 20 $\mu g/m^{-3}$.
  Total deaths = 30,170 (COPD 3,041 LNC 3,684 LRI 3,515 IHD 11,987 ST 7,943).
- Scenario 3: Lowering the national standard to 15 $\mu g/m^{-3}$.
  Total deaths = 25,079 (COPD 2,388 LNC 2,836 LRI 2,342 IHD 10,720 ST 6,794).

# Conclusion

- Air pollution deaths are about three-to-four times of traffic deaths.
- The increasing trend has been for over 20 years and will remain in a foreseeable future. Doubling the number of deaths to 100k or even higher is predictable by 2035.
- Deaths occurred in the Red River Delta, around HCMC and the upper Mekong River Delta.
- Annual economic loss is 5-7% of GDP (WTP) or 1% (loss of output/earnings).

# Policy Implications

- More stringent air quality standards (if properly enforced) would be very beneficial – The established result here suggests that the greatest marginal benefit of enforcing the current standard ($25\mu g/m^{-3}$). Stricter air quality (to 20 and $15\mu g/m^{-3}$) save lives, but by a lesser magnitude.
- Establish an early warning system to send information to citizens living around the areas of elevated concentration.
- Inclusion of health deaths and economic cost to project appraisals.
- Diversification of energy generation portfolio, shifting away from coal-burnt power plants; giving incentives to cleaner sources such as power, solar, energy efficiency appliances, and public transport projects.

# Limitations

The result reported here was dependent on many factors, unknown and uncertain to a great extent. These factors are summarized as follows:

- Poor data.
- Incomprehensive understanding of the disease epidemiology.
- Modeling process.
- Choice of subjective parameters.
- Valuation of non-market goods.
- Source of uncertainty.

# Future Extensions

- Access to high resolution data, especially monitor data, if anyone knows the contact, or have access to the data, could recommend and connect. The current model underestimates the actual impact, for example, on hospital admissions due to home treatments, or self-defense expenditure. It also did not control for the composition of the pollution (NOx, O3 etc) due to different emission sources.
- Policy to cut back emissions: need further work to decompose emission sources which is not available at this moment. We need to trace from sources to diffusion models to exposure and impacts. Future attempts should incorporate air pollution sources and modeling air dispersion using atmospheric models.
- Automated system to allow remote users access and monitor impacts.