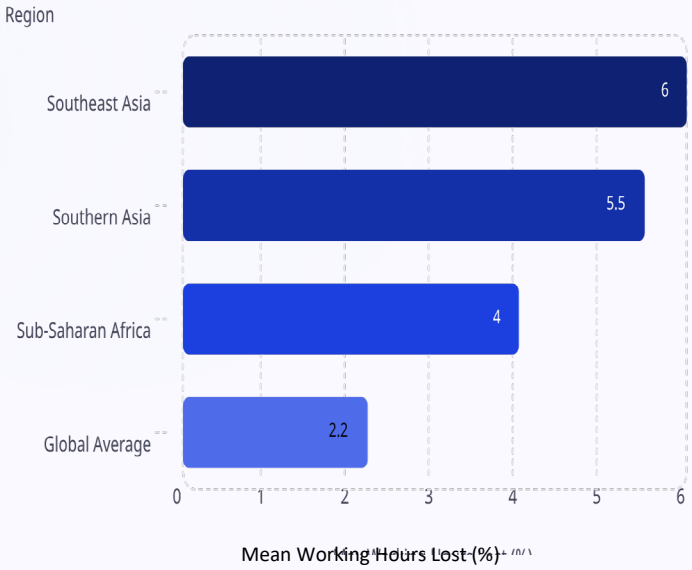
Establishment of Integrated Early Warning System in Sub-Mekong Region

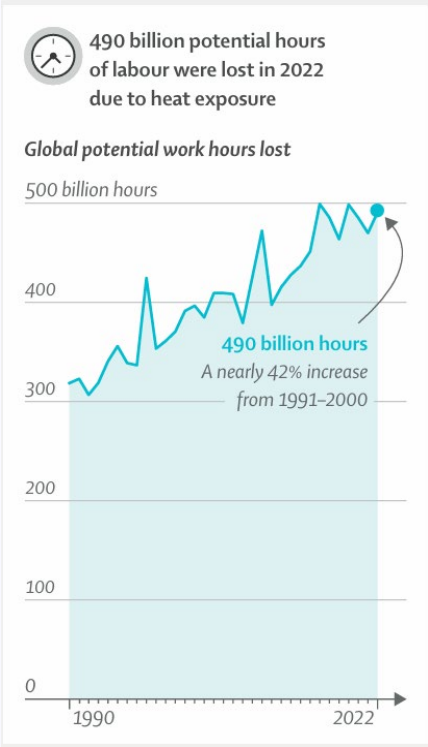
Integrated Adaptation for Air Pollution and Climate Change

Economic Losses: Heat Stress on Labor Productivity



Global Economic Impact by 2030

- Equivalent to **80 million full-time jobs** lost globally (ILO)
- **US$2.4 trillion** in economic losses from labor productivity decline (ILO)
- Direct health damage costs: **US$2–4 billion/year** by 2030 (WHO)
- Total climate-health cost: **US$2.52 trillion/year** by 2030 (The Lancet)
- Most affected sectors: agriculture and construction —low-pay, informal workers



Source: ILO (2019), WHO, The Lancet (2024)

Air Pollution & Extreme Heat: Among the World's Top Killers

According to the **State of Global Air 2024** report, air pollution ranks as the **2nd leading cause of death globally**, responsible for over 8 million deaths annually. Extreme weather events driven by climate change—including deadly heat waves—rank **10th**.

⚠ These two risk factors do not operate independently. When heat and pollution co-occur, health outcomes worsen dramatically.

🥈 Rank #2 — Air Pollution

8+ million deaths/year from PM2.5, ozone, and household air pollution

🔟 Rank #10 — Extreme Weather

Climate-driven heat events increasingly overlap with pollution episodes

State of Global Air 2024 Report

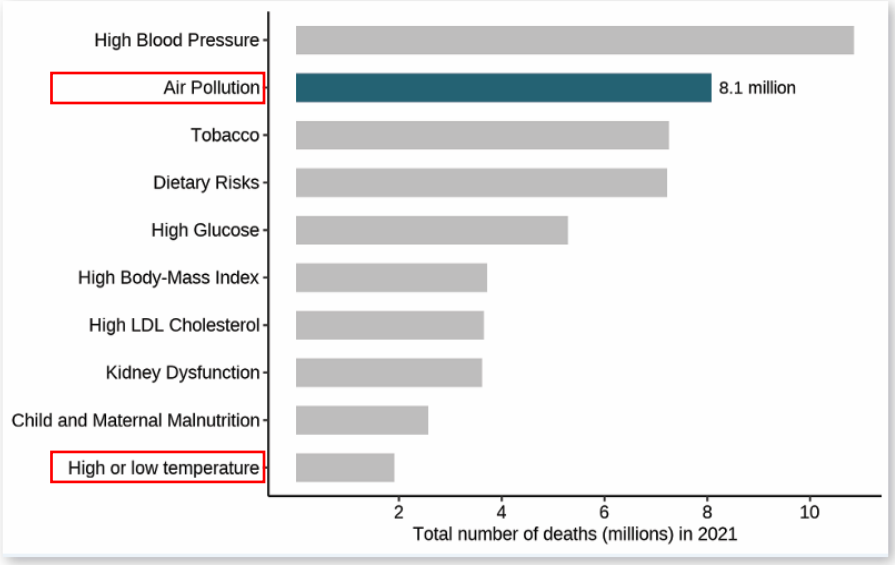


FIGURE 9. Global ranking of risk factors by total number of deaths in 2021.
Explore the rankings further via *GBD Compare*.

Southeast Asia: A Region at Disproportionate Risk

80%+ Urban Areas at Risk

Over 80% of Southeast Asian urban areas are classified as high-risk for heat stress health impacts. *(WHO)*

Extreme Heat Days Surging

From **1 day/year** (2000) → **20 days/year** (2050) → **60 days/year** (2100) under SSP5-8.5 scenario. *(PMC, 2025)*

Mortality to Multiply

Heat-related mortality projected to increase **2.5–5.5×** by 2070–2099 vs. 1980–2009 baseline. *(PMC, 2025)*

Heat ×Air Pollution: Synergistic Health Risks

Mechanisms of Interaction

→ Ozone Formation

High temperatures accelerate photochemical reactions, increasing ground -level O_3

→ PM2.5 Accumulation

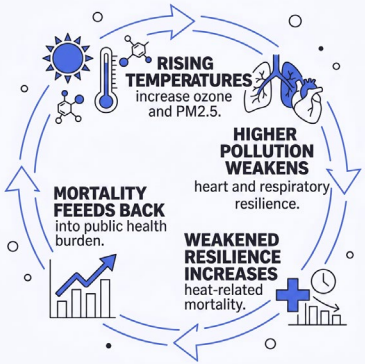
Heatwaves cause atmospheric stagnation and intensify wildfires, raising PM2.5 and haze

→ Physiological Vulnerability

Heat stress weakens cardiovascular and respiratory resilience, increasing susceptibility to polluted air

Key Biological Pathways

- Increased oxidative stress and systemic inflammation
- Elevated respiratory burden during haze events
- Cardiovascular strain compounded by heat exposure
- Reduced thermoregulation in elderly populations
- Enhanced ozone toxicity under hot, sunny conditions



⊗ Combined heat + pollution exposure creates risks **exceeding the sum of either stressor alone**

Case Study: Japan

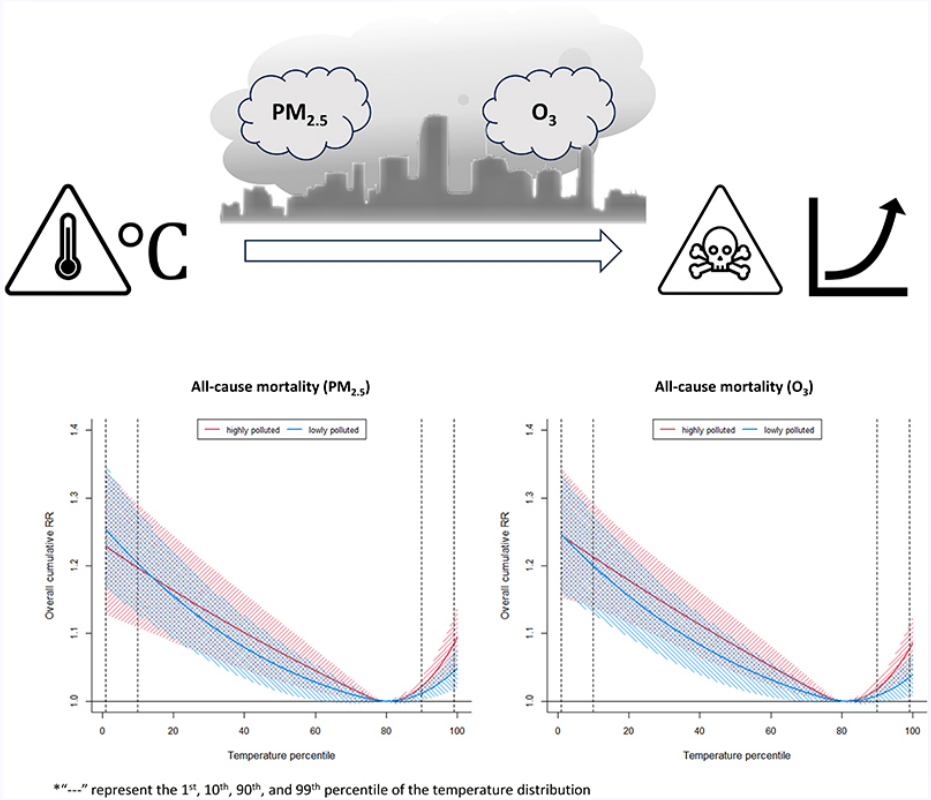
PM2.5 & Ozone Amplify Heat Mortality

Study Overview

Tajudin et al. (2024) —*Environmental Health and Preventive Medicine*
DOI: 10.1265/ehpm.24 -00108

- 20 urban areas across Japan, 2012 –2018
- Stratified analysis by **high vs. low PM2.5** and **high vs. low ozone**
- Outcome: all -cause daily mortality

Key finding: High ozone concentrations significantly **amplified heat -related mortality risk** , particularly during summer heat events in Japanese cities.



Tajudin, M. A. B. A., *et al.* (2024). *The effect modification of PM2.5 and ozone on the short-term associations between temperature and mortality across the urban areas of Japan.*

Case Study Thailand: Mortality Risk Under Combined Exposure

Study Design & Context

This nationwide Thai study examined how **co-exposure to ambient air pollution and temperature extremes** affects daily mortality across major provinces.

- Population -level epidemiological design
- Pollutants assessed: PM2.5, PM10, NO_2, O_3
- Both cold and heat extremes evaluated
- Distributed lag non-linear models (DLNM) applied

⚠ Thailand's tropical climate and rapid urbanization make it a high-risk environment where heat and pollution peaks frequently coincide.

Heat Extremes

Elevated mortality, amplified when PM2.5 simultaneously exceeds safe thresholds

Respiratory Deaths

Disproportionately higher under combined heat + pollution episodes

Cardiovascular Deaths

Synergistic effect most pronounced for cardiac causes of death

Phosri, A., Srisodaphol, W. and Sangkharat, K. (2025) 'Combined effects of ambient air pollution and temperature on mortality in Thailand'

Epidemiological Evidence: Heat–Pollution Interaction

Study	Location	Pollutants	Key Finding
Liu et al. (2023)	620 cities, 36 countries	PM10, PM2.5, NO2, O3	Heat mortality risk: 5.3% (PM10=10 μg/m³) → 12.8% (PM10=90 μg/m³); O3 amplifies to 12.5%
Tajudin et al. (2024)	Japan (urban)	PM2.5, O3	High ozone significantly intensified heat-related mortality risk
Scortichini et al. (2018)	Italy (25 cities)	PM10, O3	Heat effects on mortality stronger during high-ozone days
Rai et al. (2023)	Multi-country (482 cities)	PM2.5, O3	Air pollution amplified cardiorespiratory mortality under heat
Nakai et al. (1999)	Tokyo, 1980–1995	O3, NO2	Temperature and ozone both independent risk factors for heatstroke

Combined heat + high-pollution exposure consistently exceeds the mortality risk of either stressor alone—a synergistic, not merely additive, effect.

PRIORITY RECOMMENDATION

Establish Integrated (Heat Stress and Air Quality) Early Warning Systems

Issue joint alerts across Southeast Asian cities when **both Heat and PM2.5/ozone thresholds** are exceeded simultaneously —enabling timely public health responses.

Embed Health in Adaptation Plans

Integrate health outcomes into national climate adaptation strategies to address heat and pollution together.

Reduce Emissions

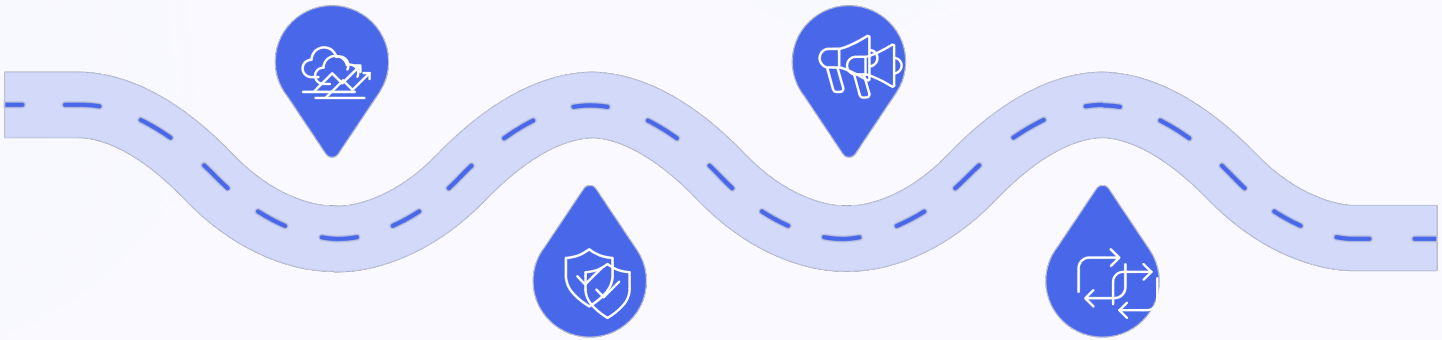
Simultaneously lower heat island effects and air pollution burdens through coordinated emission controls.

Regional Cooperation

Foster cross-border collaboration for transboundary haze and shared early warning data. *(WHO; IPCC AR6)*

Contribution to the Sub-Mekong Region

Utilization of Integrated (Heat Stress and Air Quality) Early Warning System Results



Forecast
Heat Stress and air pollution alerts

Advisories
Public receives health guidance and actions

Activation
Authorities enact bans and closures

Feedback
Outcomes inform emissions controls and policy

The early warning system enables a coordinated response chain —from forecast issuance to on-the-ground protective action— targeting open burning, traffic emissions, and public health preparedness across Mekong sub-region countries.

Burn Bans & Fire Control
Preemptive restrictions on agricultural burning when forecast thresholds are breached.

Health Advisories
Targeted guidance for hospitals, elderly care centers, and at-risk communities.

School & Outdoor Activity Closures
Protect vulnerable populations during forecast high-pollution episodes.

Policy & Emission Controls
Real-time data feeds regulatory response and long-term mitigation planning.

Tentative Framework of Heat & Air Quality Early Warning System

【Region】 Sub-Mekong Region
【Period】 5 Days or 1 week forecast (TBC)
【Targets】 (Air quality) $PM_{2.5}$, PM2.5 emitted from open burning, O_3
(Meteorology) Temperature, humidity etc.
(Index) Air quality, heat stress and integrated index

Weather forecasting

AQ monitoring and other observation (ground & satellite)

Emission inventory (incl. from satellite data of hot spot of open burning)

Regional meteorological model

Chemical Transport Model

Model-bias correction with AI

Integrated index converter

Empirical/ Statistical Forecasting

Forecasting & Warning: Integrated index map and regional warning level

Convert into Mitigation/adaptation Measures

Pollution Causers

Policy Makers

General Public

Heat Stroke and Air Quality Early Warning System

Protecting Health through Integrated Monitoring, Prediction and Risk Communication

1. Data Inputs

Air Quality Monitoring
PM2.5, O3, NO2, SO2, CO, AQI

Meteorological Data
Temperature, Humidity, Wind, Solar Radiation, Precipitation

Forecast Data
Weather forecast, Air quality model outputs

Population & Health Data
Demographics, vulnerable groups, hospital visits, health surveillance

Land Use & Emissions
Traffic, industry, biomass burning, land use

Event & Activity Data
School, outdoor events, construction, etc.

2. Monitoring & Forecasting

Real-time Monitoring

- Air quality stations
- Meteorological stations
- Satellite observations
- Data assimilation

Prediction & Forecasting

- Air quality forecasting (e.g., PM2.5)
- Weather forecasting (e.g., heat index)
- Integrated modeling
- 24–72 hour forecasts

3. Risk Assessment

Air Quality Index (e.g., PM2.5) > < Heat Stress Index (e.g., WBGT, Heat Index) × Population Vulnerability = Combined Risk of Heat Stroke and Air Pollution

4. Warning Levels

Level 1 (Low)	Level 2 (Moderate)	Level 3 (High)	Level 4 (Very High)
No action needed	Be aware, stay hydrated	Limit outdoor activities	Avoid outdoor activities, take precautions

5. Communication & Action

Multi-channel Alerts
Mobile apps, SMS, websites, social media, TV, radio, digital signboards

Targeted Messages
General public, elderly, children, outdoor workers, schools

Recommended Actions
Hydration, rest, avoid outdoor exertion, use masks when needed, seek medical help if symptoms occur

Institutional Response
Schools, local governments, health institutions, workplace guidelines, event management

6. Collaboration & Capacity Building

Multi-sectoral collaboration
Government, academia, private sector, communities

Data sharing & integration
Open data, standards, interoperability

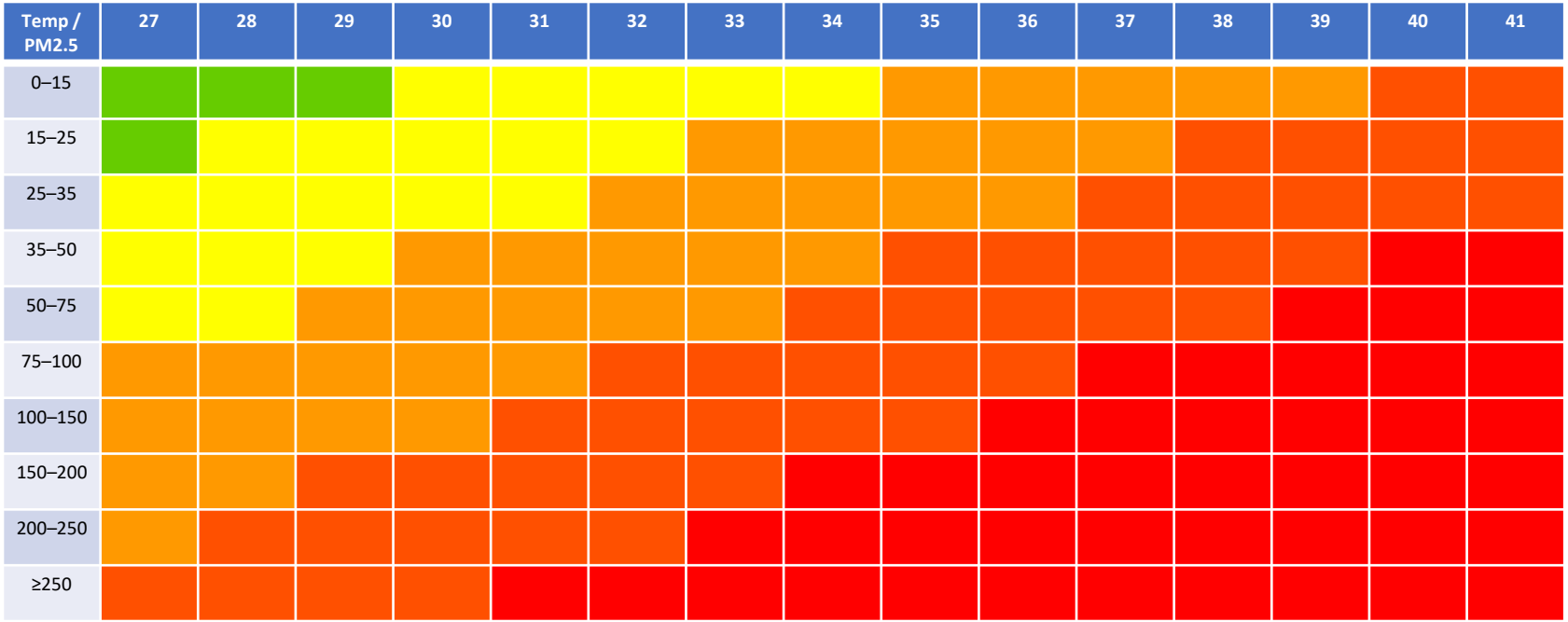
Training & awareness
Capacity building, public education

Evaluation & improvement
System evaluation, continuous improvement

Heat Stress & Air Quality Index

This matrix is intended for illustrative purposes only.

- PM2.5 concentrations are based on the WHO air quality guidelines,
- While temperature classifications are adapted from the Heat Index published by the Government of Thailand.



Recommendations for Action

1

Integrated Early Warning Systems

Establish **integrated (heat-and-air-quality) early warning systems** across Southeast Asian cities — issuing joint alerts when both temperature and PM2.5/ozone thresholds are exceeded simultaneously.

2

Integrated Climate & Air Quality Policy

Embed health outcomes into national climate adaptation plans; reduce emissions to simultaneously lower heat and pollution burdens. Foster regional cross-border cooperation.

3

Occupational Heat & Pollution Protection

Enforce mandatory rest breaks, hydration access, and adjusted schedules for outdoor workers in agriculture and construction during compound heat-pollution events.

Institutional Framework

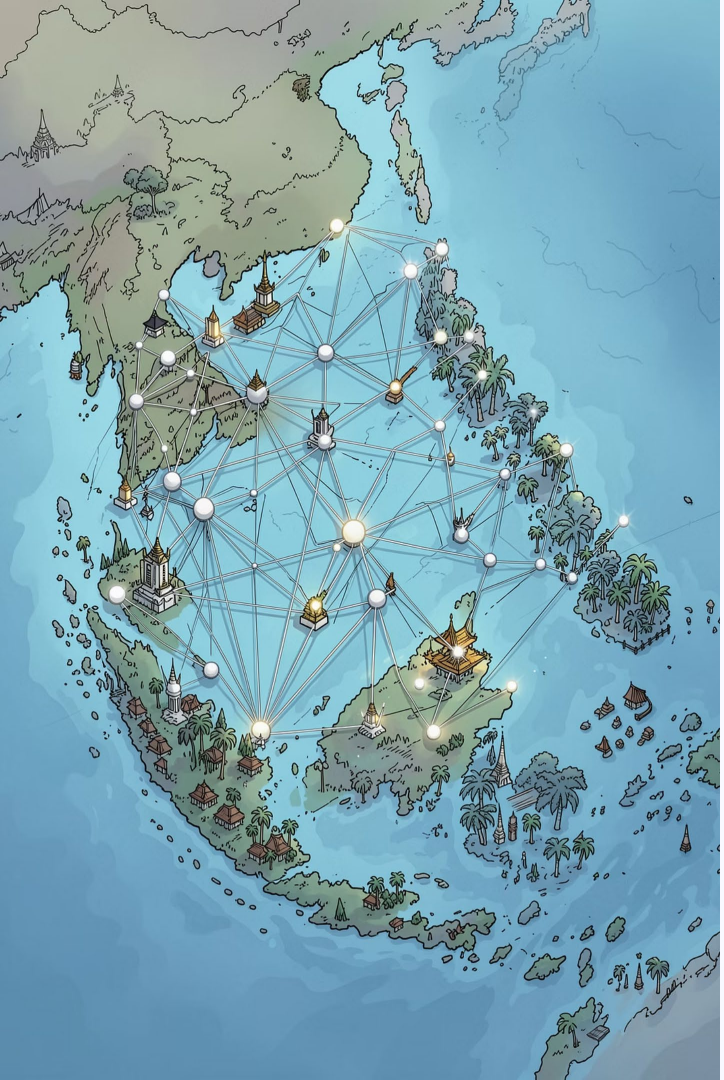
ACAP — Air Pollution

Hokkaido University Founded 1876 — Heat Stress

IGES Institute for Global Environmental Strategies

Local + National + Regional

Government Actions



ASEAN ALIGNMENT

Contribution to the Whole ASEAN Region

This project directly supports the **Second ASEAN Haze-Free Roadmap (2023–2030)**, advancing key strategies through integrated early warning and regional cooperation —with the Mekong sub-region as the strategic entry point.

1

Strategy 2: Subregional Strategies

Developing and implementing targeted subregional air quality management approaches for the Mekong countries.

2

Strategy 3: Land & Forest Fire Management

Developing and improving early warning capacities and fire detection systems to address agricultural land and forest fires.

3

Strategy 6: National Policy Strengthening

Further developing IEC tools —including hotlines, fire reporting websites, and compliance reward schemes for the private sector.

4

Strategy 8: Public Awareness

Intensifying awareness-raising and information dissemination activities across member states using AQEWS outputs.

5

Meeting WHO Interim Targets 3

Success is measured by achieving national PM2.5 air quality targets aligned with the World Health Organization's strict Interim Targets 3.

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