Air Quality Management in Mongolia : Insights from Science and Policy

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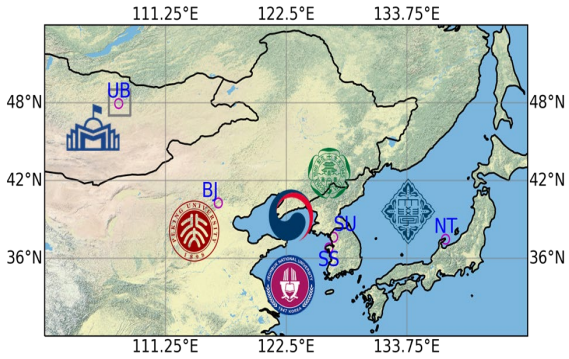
* Fine Particle Research Initiative in East Asia Considering National Differences Project

01. Background : Northeast Asia and Mongolia

The FRIEND Project (K-NRF research project on Fine Particle Pollution Improvement, Yr. 2020~2025)

AQNEA : Air Quality in NE Asia
(PI : J.-H. Woo, Co-PI : Zig Klimont))

Collaborative AQ Monitoring in NE Asia (PI : J.Y. Lee)



K-MOE | NAIR | NIER

Sub Project 3 : Future AQ Projection (Integrate Assessment in NEA)

Sub Project 2 : AQ Forecasting (K-CTM)

Emissions

Verification

Validation

Downscaling

Sub Project 1 : Science Basis (Monitoring, Smog Chamber)

Parameters

Sub Project 4 : Region-specific Management (Korea)

NEACAP-NEASPEC | Korea-China-Japan AQ Cooperation | Local Government

H.-M. Lee et al., Improvement of the anthropogenic emission rate estimate in Ulaanbaatar, Mongolia, for 2020–21 winter, Environmental Pollution 349 (2024)

02. Mongolia Air Pollution : Monitoring and CTM-based Scaling on Emissions (FRIEND)

Finding Valid Emissions : Monitoring-Modeling-Scaling

<Flowchart of scaling factors estimation process>

Baseline Emissions

CEDS Emis. 2019

CTM (GEOS-Chem)

First guess for all species

Calculate scaling factors (σ) for gases and carbons

$\sigma_i = {}^{C_i(obs)}/_{C_i(mod)}$

i = CO, SO_2, NO (NO_2), NH_3 (NH_4^+), OC, EC

Inert species

Update σ using regressions from three calculations

$\sigma_i = {}^{\Delta C_a(obs)}/_{\Delta C_a(mod)}$

i = CO, OC, EC

a = CO, OC, EC

NH_3 richness determination

NO and NH_3

Repeat until best matches NO_3^- and NH_4^+ concentrations

$\sigma_i = {}^{\Delta C_a(obs)}/_{\Delta C_a(mod)}$

i = NO, NH_3

a = NO_3^-, NH_4^+

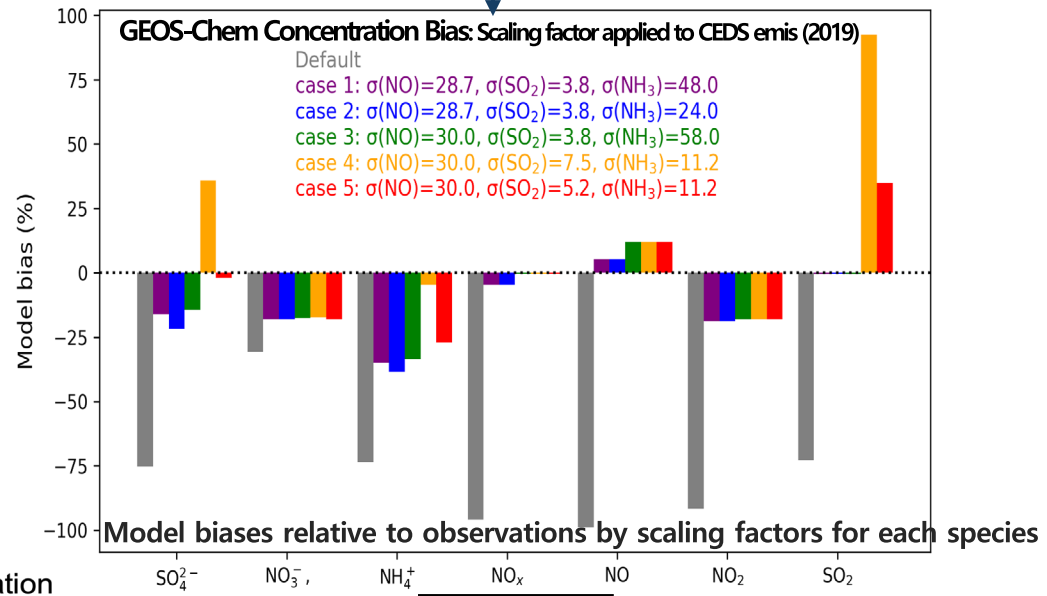
SO_2

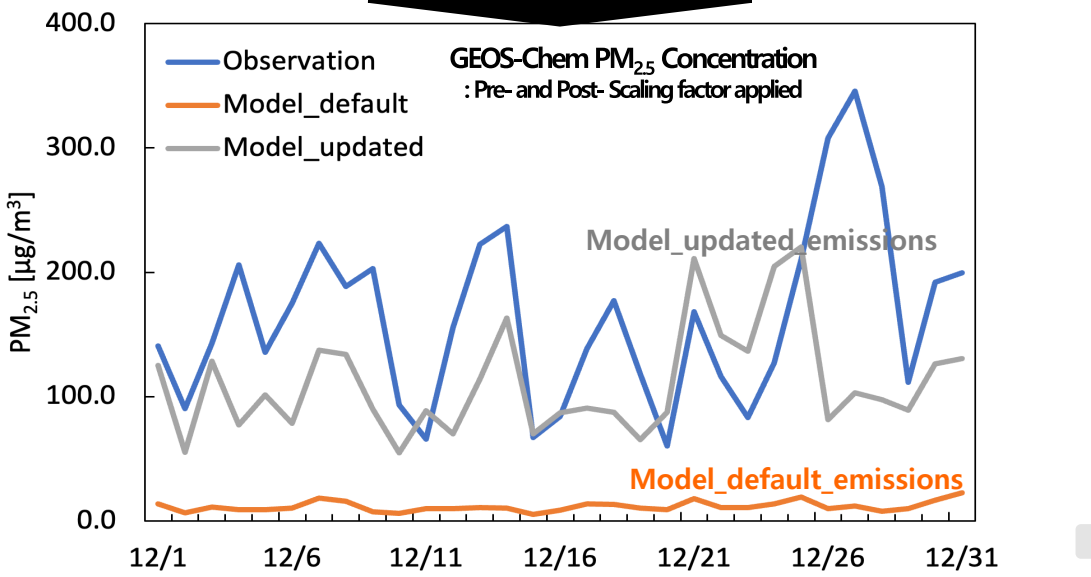
Repeat until best matches SO_4^{2-} concentration

$\sigma_i = {}^{\Delta C_a(obs)}/_{\Delta C_a(mod)}$

i = SO_2

a = SO_4^{2-}





* Comprehensive Regional Emissions for Atmospheric Transport Experiments

03. Mongolia Air Pollution : Bottom-up Emissions Inventory Development

Northeast Asian Emission Inventory Development : CREATEv4.0 (2022)*

Funded by 환경부 국가미세먼지정보센터 (NAIR)

- Northeast Asian emission inventory development research by SNU, funded by ***Korea's National Air Emission Inventory and Research Center*** **(NAIR)**
- **CREATEv4.0 (2022)** represents the latest update of the existing Asian anthropogenic emission inventory (CREATE)
- **Mongolian emissions updated** using recent energy and non-energy statistics (IEA World Energy Outlook 2024, Mongolian Statistical Yearbook 2024)

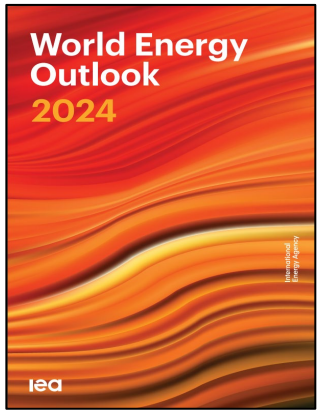
CREATE ver. 4.0 Emission Inventory Framework

	China	N.Korea	Japan	Mongolia
Activity data update	• China Energy Statistics Yearbook (CESY) • China Statistics Yearbook (CSY) International Road Federation (IRF) • Food and Agriculture Organization (FAO)	• International Energy Agency (IEA) • Statistics Korea (KOSTAT) • Food and Agriculture Organization (FAO)	• International Energy Agency (IEA) • Japan Statistical Yearbook (JSY) • Food and Agriculture Organization (FAO)	• International Energy Agency (IEA) • Mongolia Statistical Yearbook (MSY) • United State Geological Survey (USGS)
	China	N.Korea	Japan	Mongolia

Updated CREATE Emission Inventory (2022)

Mongolia Emissions (Activity data)

Energy activity



<IEA World Energy Outlook 2024>

Non-Energy activity

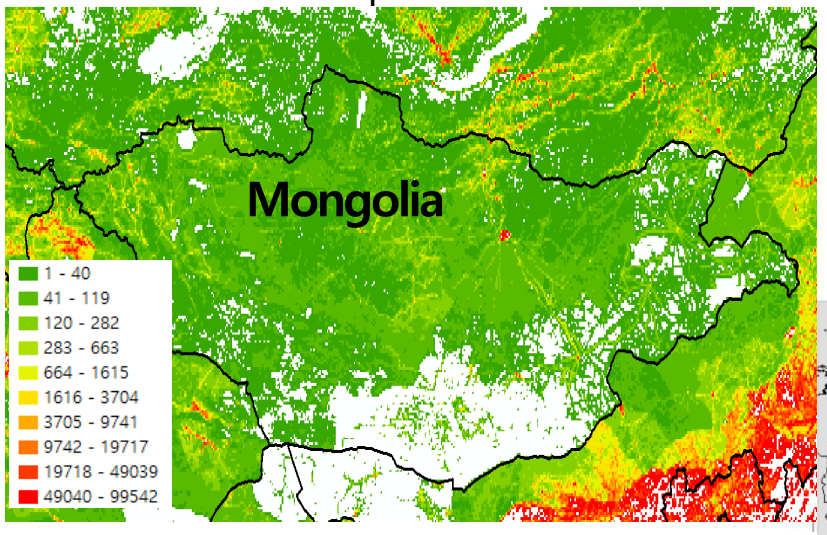
<Mongolian Statistical Yearbook 2024>

*SMOKE : Sparse Matrix Operator Kernel Emissions

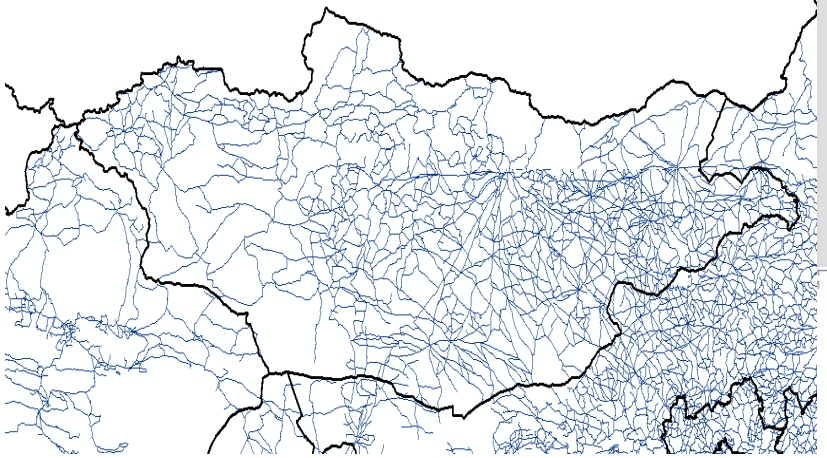
03. Mongolia Air Pollution : Bottom-up Emissions Inventory Development

CREATE Modeling Emissions Inventory using SMOKE* : Asia, Mongolia and Ulaanbaatar

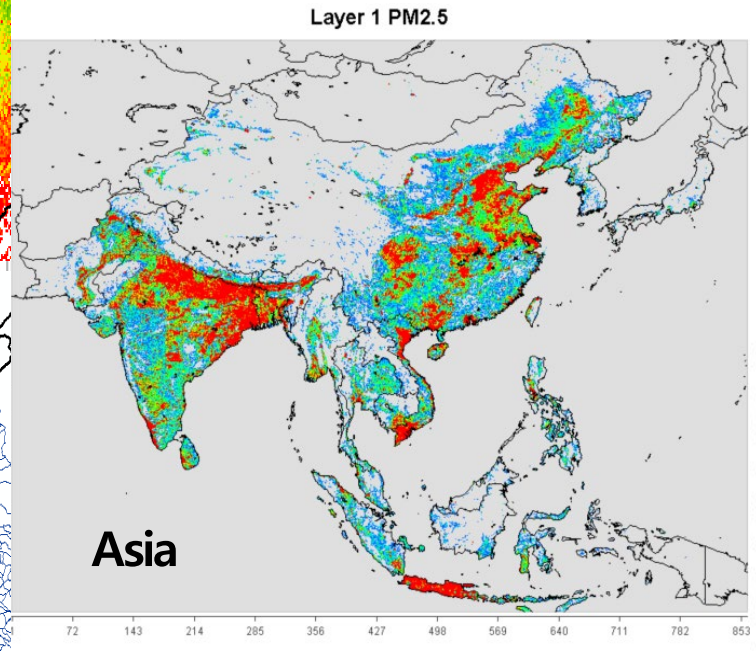
Population



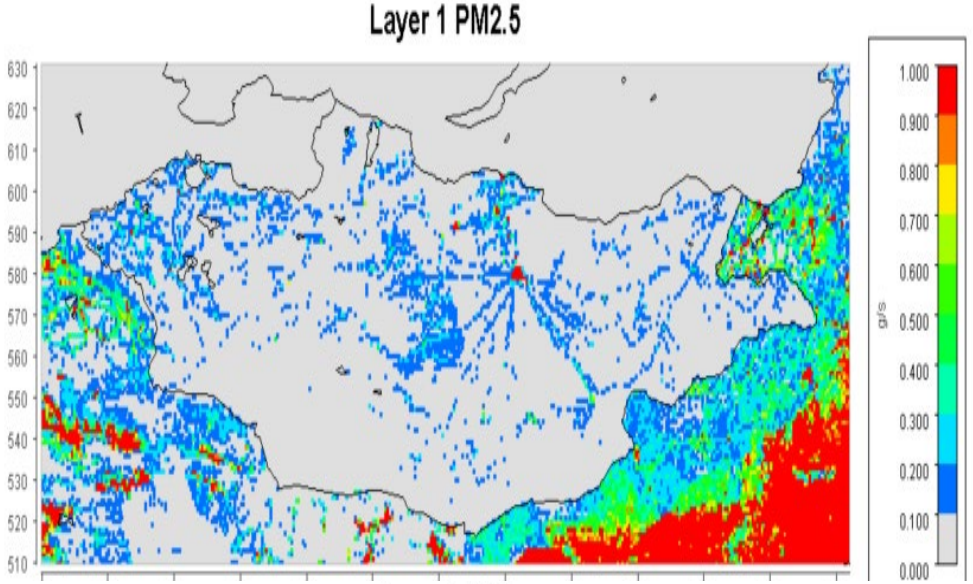
Road



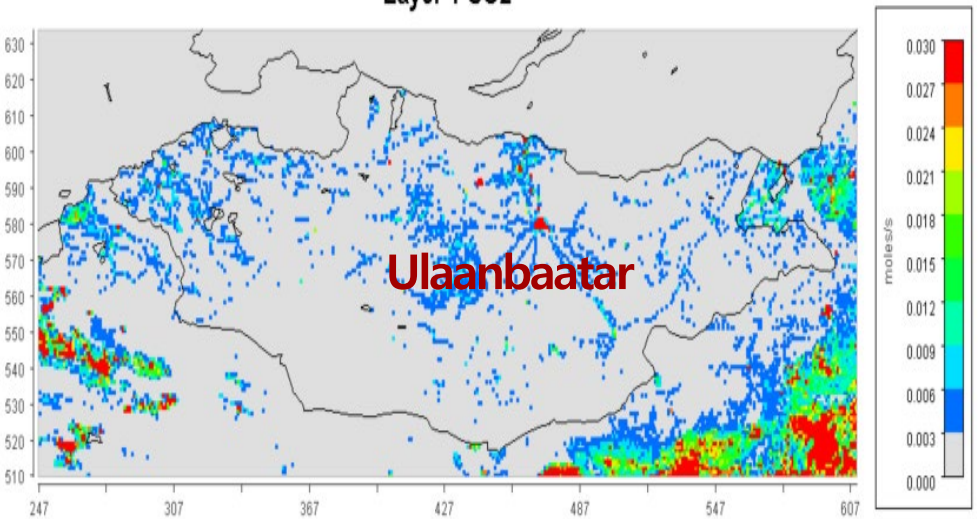
Layer 1 PM2.5



Layer 1 PM2.5



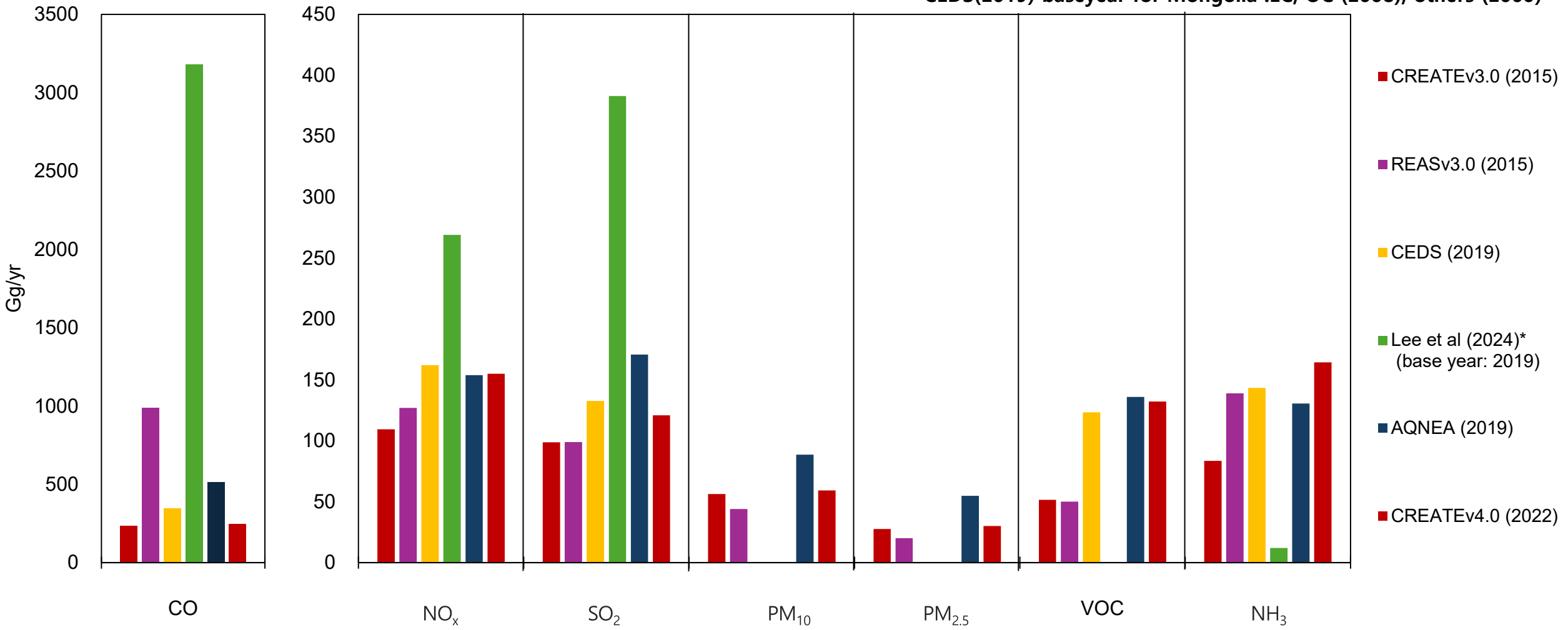
Layer 1 SO2



03. Mongolia Air Pollution : Bottom-up Emissions Inventory

Comparison of Emission in Mongolia

*** Annual Ulaanbaatar emissions calculated using Lee et al., 2024 emission rates**
CEDS(2019) baseyear for Mongolia :EC, OC (2008), others (2000)

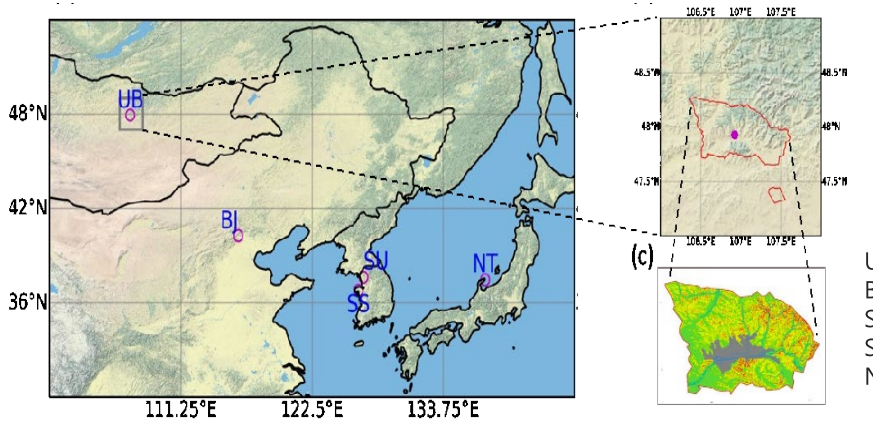


Source : 1) CREATE : Woo et al., 2025, 2) CEDS : hoesly et al., 2019, 3) Lee et al., 2024 4) GAINS-AQNEA : IIASA 2023

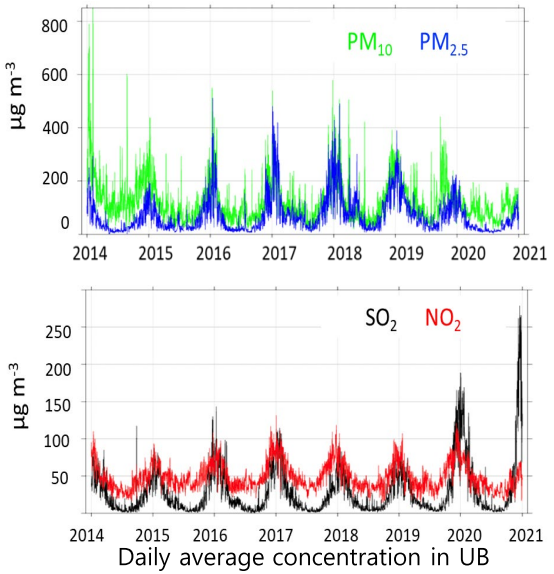
Source : J. Jo et al., Spatial characteristics of nitro- and oxy-PAHs during winter in Northeast Asia, Atmospheric Environment 356 (2025)

04. Mongolia Air Pollution : Monitoring-based Contribution & Risk Assessment (FRIEND)

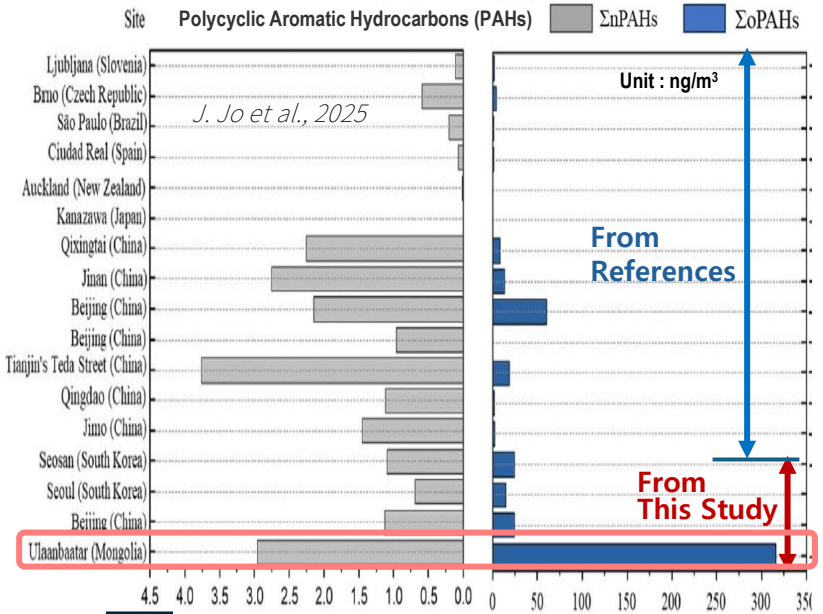
Monitoring-Concentration-Risk Assessment

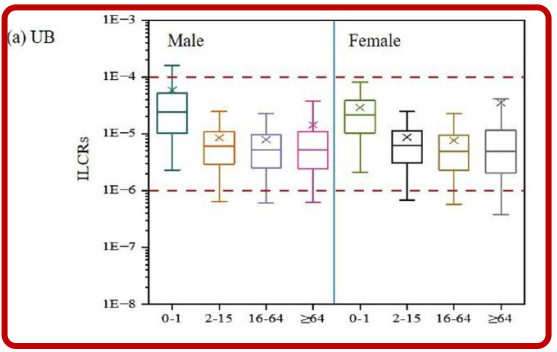


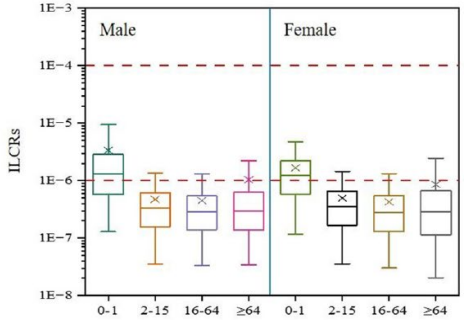
UB: Ulaanbaatar, Mongo
BJ: Beijing, China
SU (SE) Seoul, Korea
SS: Seosan, Korea
NT: Noto, Japan)

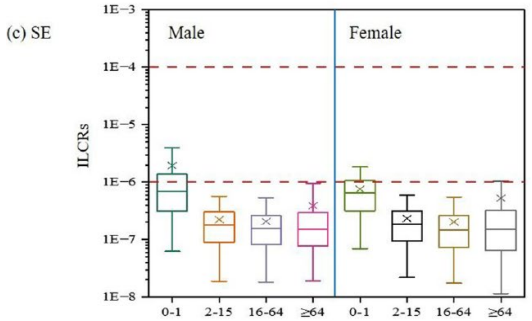


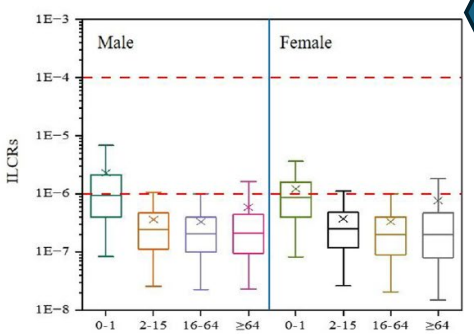
Soyol-Erdene et al., 2021; H.-M. Lee et al., 2024



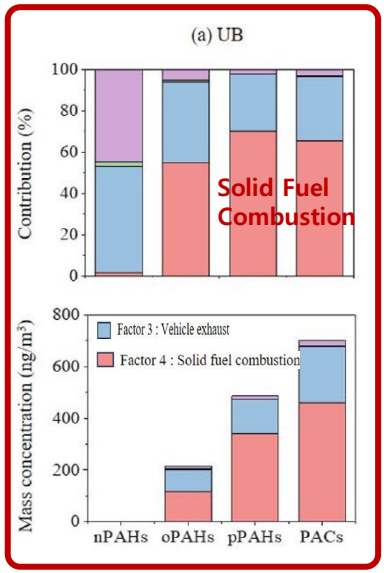


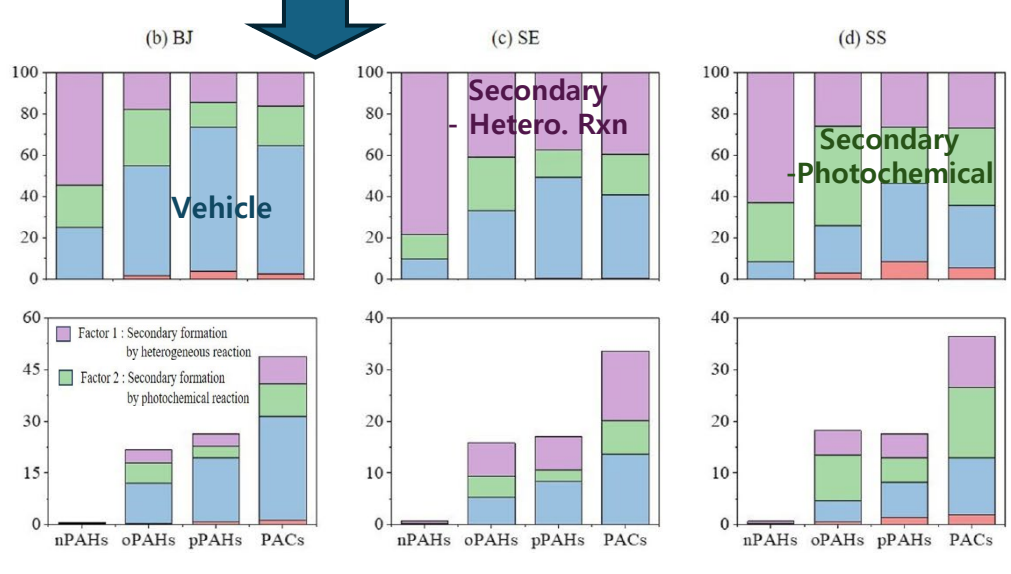






Estimated Risk (Incremental Lifetime Cancer Risk :ILCRs) of PAHs by inhalation group by gender and age





Contribution ratios and **mass concentrations** of four factors to PAC(Polycyclic Aromatic Compounds) groups

Source : JH Hong et al., Citizen Preferences for Air Pollution Policies in Mongolia, submitted

05. Mongolia's Air Quality Management : Policy Preferences on Improving Air Quality

Investigate public preferences for air pollution mitigation (WTP vs. WTW)

1) The Crisis in Ulaanbaatar

- 1,400 premature deaths annually from air pollution (10% of total deaths)
- Economic cost: 27.9% of city's GRDP(Gross Reginal Domestic Product) in health impacts

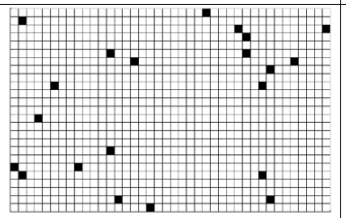
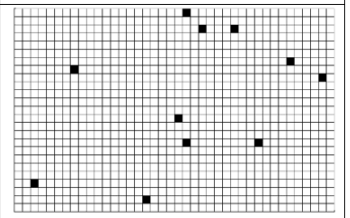
2) Research Gap

- **Limited research on public preferences** for air pollution policies
- **Previous policies failed** due to disconnect between top-down design and citizen needs
- Need to **understand what citizens actually want** and **how they prefer to contribute**

3) Research Design

- **Choice Experiment with 842 valid respondents** in Ulaanbaatar
- Split-sample design: **Money group vs. Labor group**
- Three key attributes tested
  : **Visibility improvement** (bad → medium → good)
  : **Mortality reduction** (current → 50% reduction → global average)
  : **Policy interventions** (electricity, waste disposal, transportation)

<Choice Set Example>

Description	A. Project X (Current situation)	B. Project O (After implementing the project)
The average level of how well you can see ahead in winter time	 Bad	 Medium
For every 100,000 people, the people **die** from diseases by air pollution in 10 year. ■: death cases	 **2147** (This means that I have a **0.21%** chance of dying from air pollution each year.)	 **1074** (This means that I have a **0.11%** chance of dying from air pollution each year.)
Additional policy for mitigating air pollution	Nothing	 Construct eco-friendly waste disposal facilities
An increase in your electricity bill for 5 years	0 MNT/month	2,000 MNT/month
I would vote for	□	□

➔ ***Investigate public preferences for air pollution mitigation using both monetary (willingness to pay: WTP) and non-monetary (willingness to work : WTW) contribution methods***

Source : JH Hong et al., Citizen Preferences for Air Pollution Policies in Mongolia, submitted

05. Mongolia's Air Quality Management : Policy Preferences on Improving Air Quality

Policy Implication & Recommendations

4) Major Findings

- **higher values for Labor-based contributions** : WTW 15-74% higher than WTP
- Diminishing returns pattern: **Highest value for escaping worst conditions**
- **Policy preference ranking**: : 1st: Eco-friendly **electricity generation/** 2nd: Eco-friendly **waste disposal/** 3rd: **Public transportation** expansion

5) Key Insights for Policymakers

1 **Use Multiple Contribution Methods**	- Traditional monetary surveys **underestimate public support** - **Labor-based contributions reveal true preferences in resource-constrained settings** - Design flexible participation pathways
2 **Prioritize "Quik Wins"**	- Focus on **escaping worst conditions first** (highest marginal utility) - **Build visible improvements** to create momentum and trust - Stage implementation: **immediate relief → long-term structural reform**
3 **Align with Public Preferences**	- **Eco-friendly electricity generation** has strongest public support - Citizens understand need for **upstream/systemic solutions** - Move beyond household-level interventions to infrastructure transformation

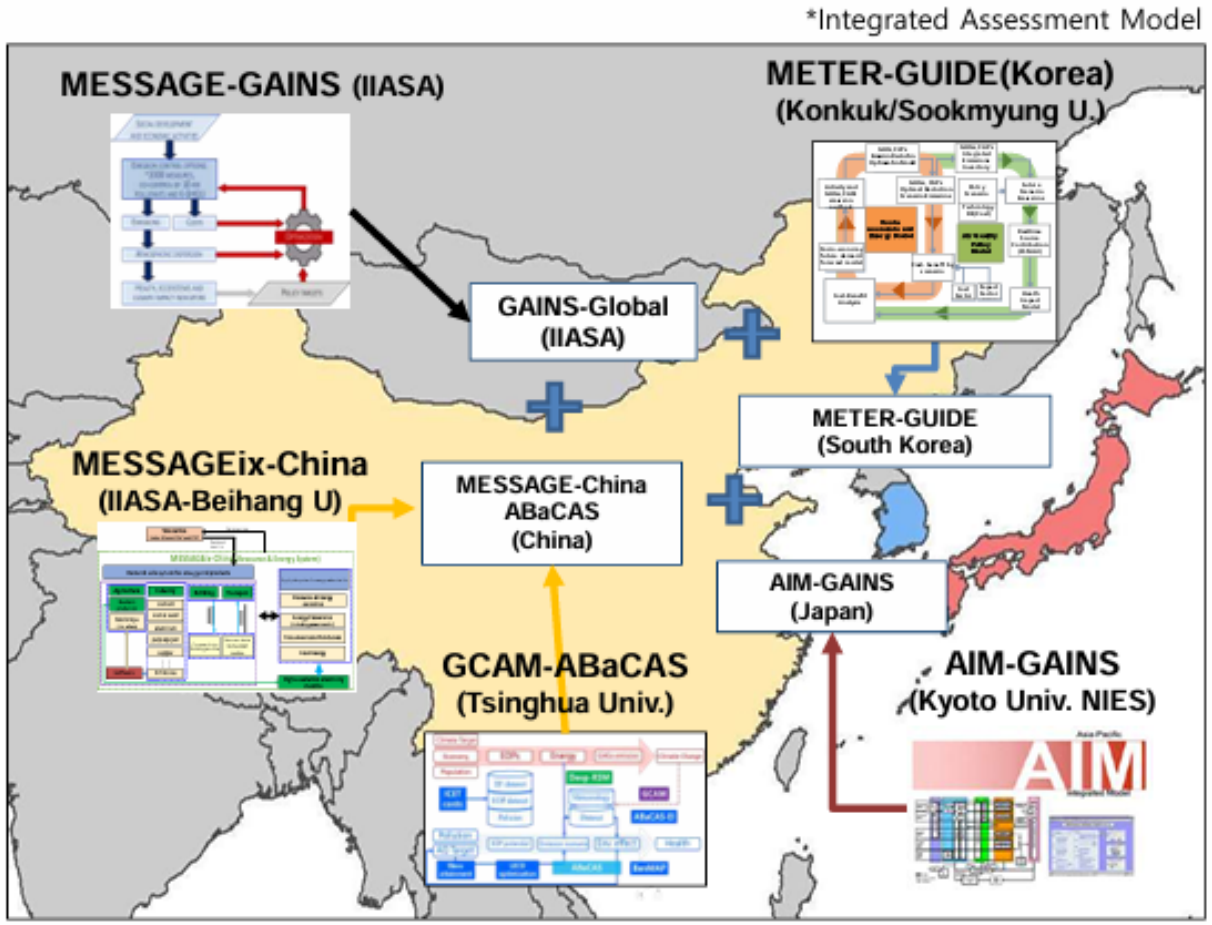
6) Recommended Strategy: Two-pronged approach

- **Immediate measures**: Subsidized **clean heating**, **expanded transit**
- **Structural reforms**: **Clean energy infrastructure**, **regulated development**

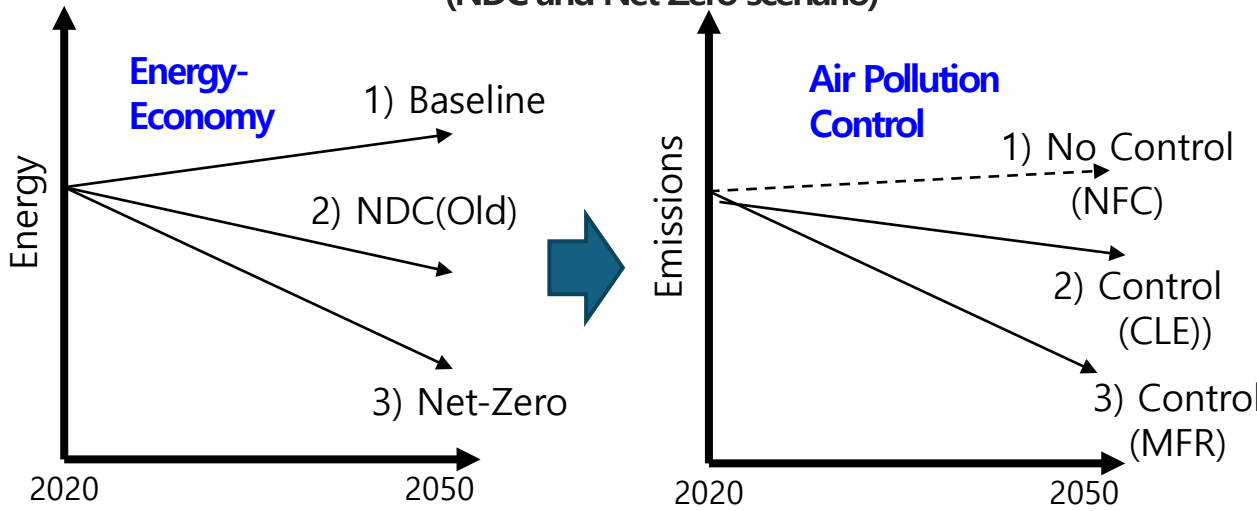
06. Future AQ Management : Insights from Regional Cooperation: FRIEND-AQNEA*

AQNEA: Future Air Quality in NE Asia under Carbon Neutrality

AQNEA Integrated Assessment Modeling(IAM) Framework



Energy and AQ scenario pathway setup (NDC and Net-Zero scenario)



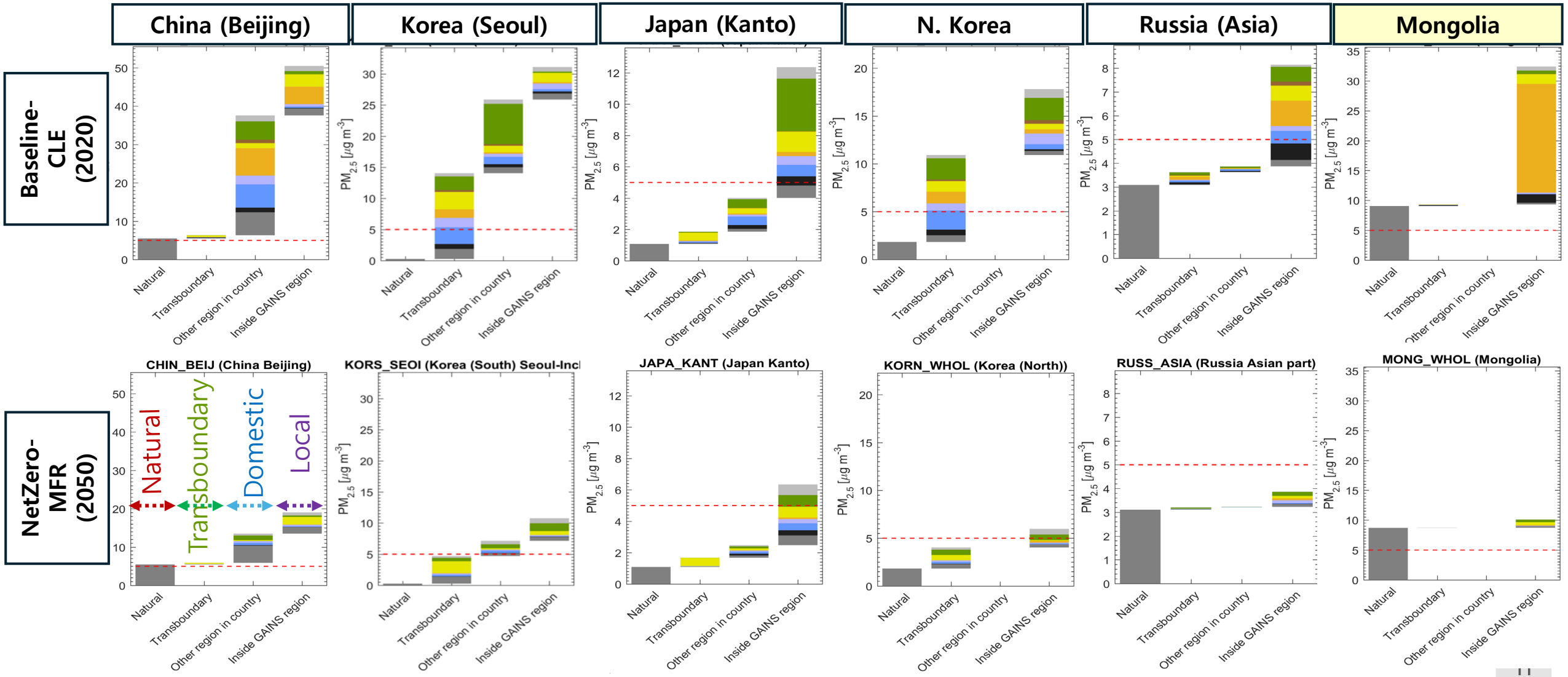
Socioeconomy – Energy – Air pollution Scenarios

Socio-economy	Energy Scenario pathway		Air Pollution Control	
SSP2	**Baseline**	No policy scenario	**No Control**	No Further Control (NFC) scenario
	NDC (Old)	Middle range scenario	**Control (CLE)**	Current Legislation(CLE) scenario
	Net-Zero	**Carbon-Neutrality scenario**	**Control (MFR)**	Maximum Feasible Reduction(MFR) scenario

* NDC : Nationally Determined Contribution

06. Future AQ Management : Insights from Regional Cooperation: FRIEND-AQNEA

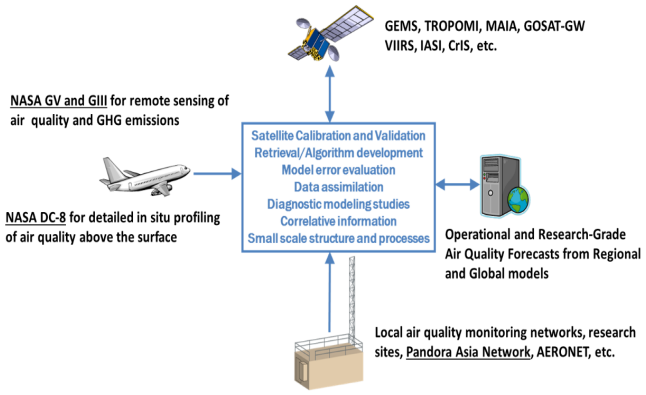
AQNEA: Future Air Quality in NE Asia under Carbon Neutrality

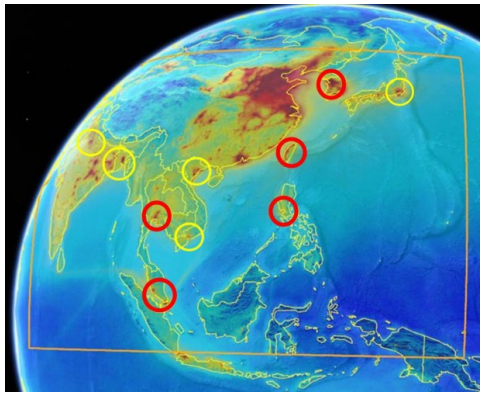


03. Mongolia Air Pollution : Science and Policy Cooperation

AQNEA EI in Support of NASA/NIER ASIA-AQ

ASIA-AQ Aircraft Field Campaign





ASIA-AQ inventory Development

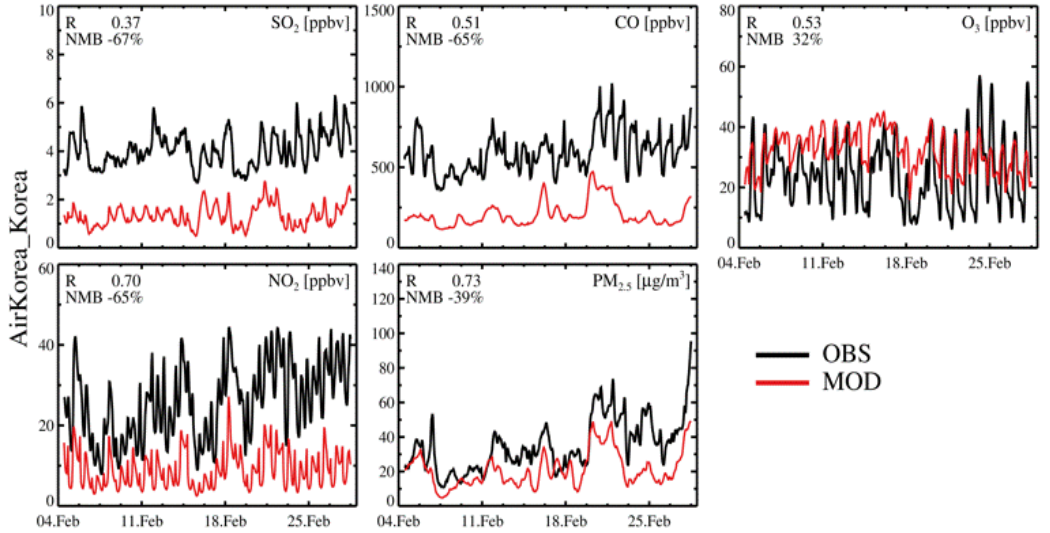
1. **ASIA-AQ v1**
   - MOSAIC-AQNEA (incl. CAPSS) + CREATE v3.0 emissions inventory
2. **ASIA-AQ v2**
   - Harmonize MOSAIC-AQNEA + GAINS-AQNEA emissions [Korea, China]
3. **ASIA-AQ v3**
   - **CO emissions**
     - **South Korea** : "Industrial process", "Energy", and "On-road vehicle': update emission factors* ** CO:NOx, VOC:NOx ratio of *COPERT database*
     - **China** : Residential sector; updated using MEIC emission inventory, Update monthly variation
     - **North Korea** : Update Residential sector (latest energy statistics imported). Update monthly variation (literature)
   - **International Shipping** : Update the base year ship emissions using ECLIPSE v6b CLE 2020 database

Support
CTM Forecasting

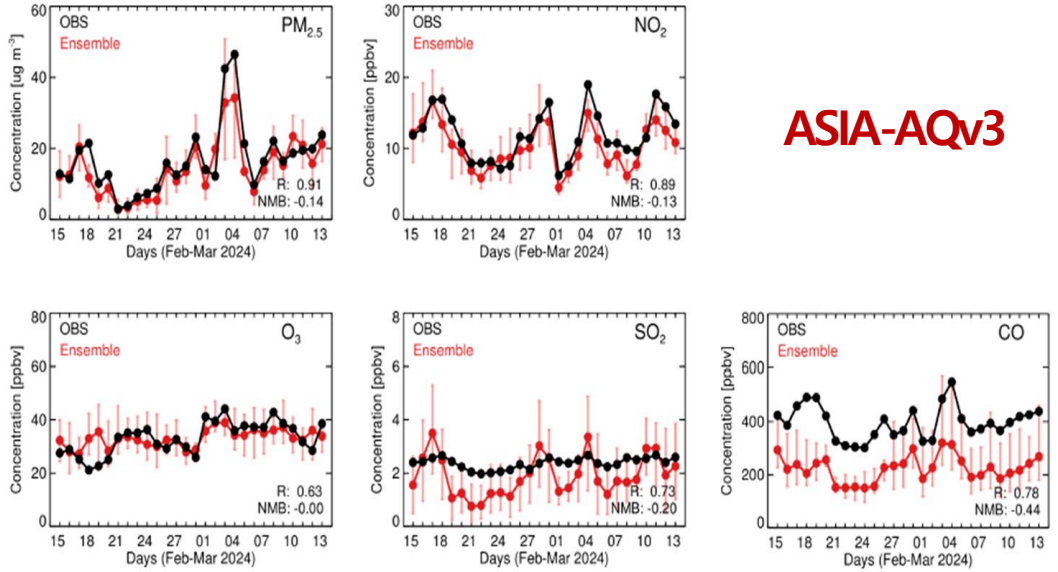
Support
Emissions Verification

Korea, WRF-GC

ASIA-AQv1 EI

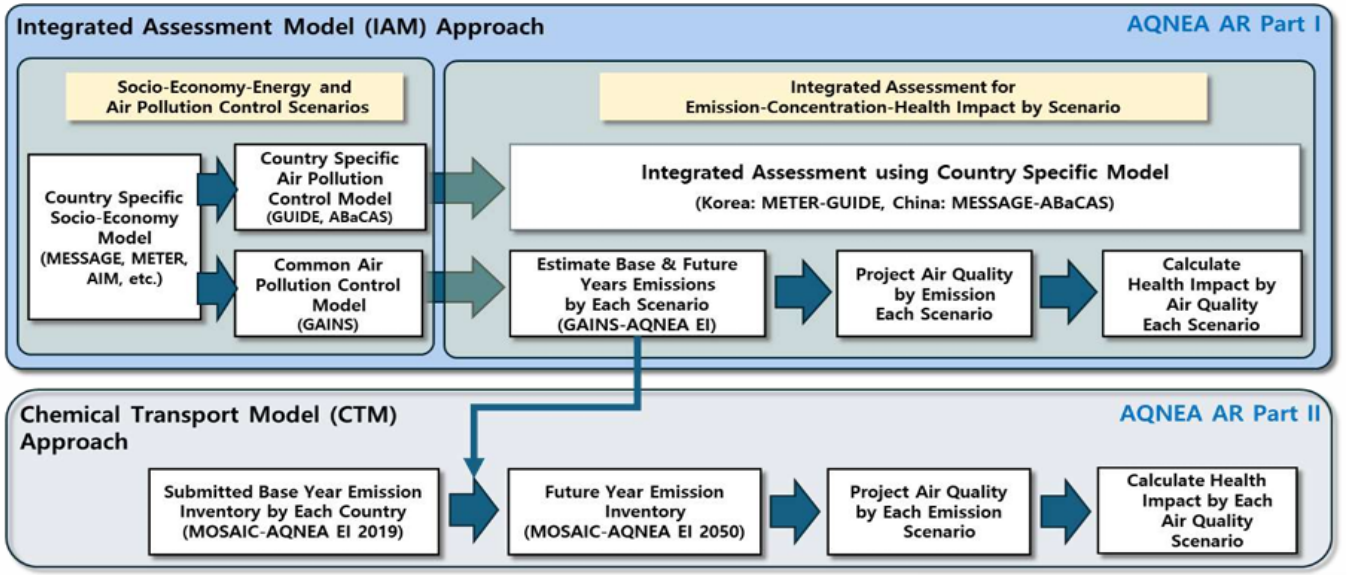


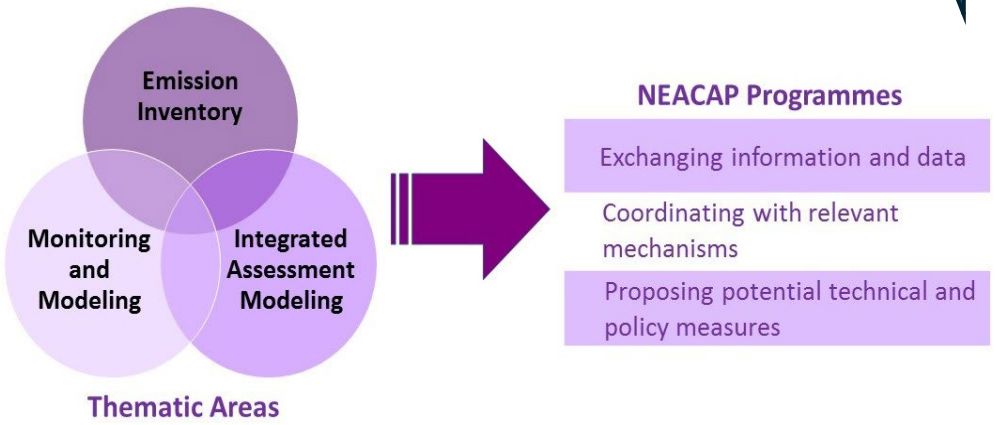
ASIA-AQv3



06. Future AQ Management : Insights from Regional Cooperation: FRIEND-AQNEA

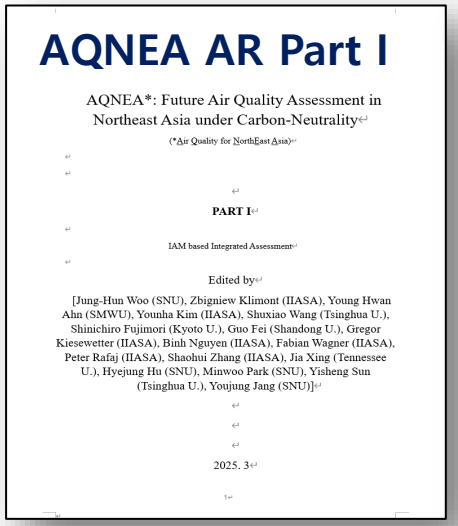
AQNEA: Assessment Report (AR) Part I (IAM-based) and Part II (CTM+IAM)

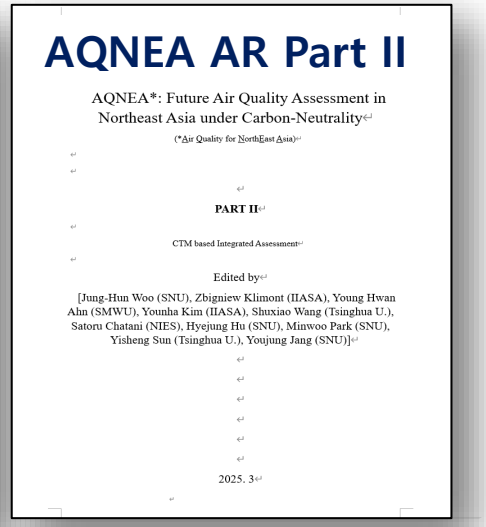




AQNEA Objectives

- **Establish** Network of Experts in NE Asia
- **Develop** Integrated AQ Management Strategies
- **Support** International Cooperation Frameworks





07. Summary

Key Issues

- Among world's most severe winter air pollution (UB)
- Heavy health & economic burdens

Management Policy Needs

- Accurate emissions estimation
- Science-based & socially accepted policy development

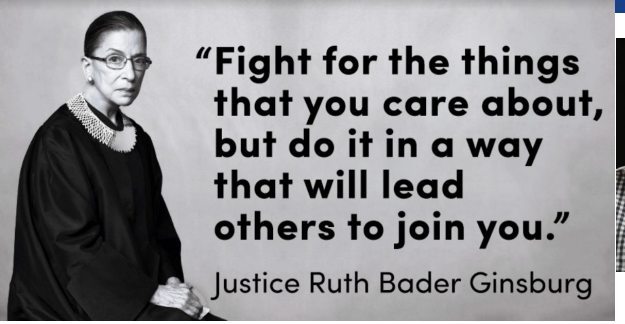
Research Insights from FRIEND-AQNEA

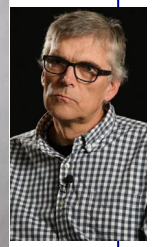
- Carbon neutrality + strict air pollution controls
  → cleaner air (Mongolia & NE Asia)
- International research stronger within regional cooperation

Way Forward

- Leverage **NEACAP expertise & networks**
- Integrate **science + society + cooperation** for sustainable solutions

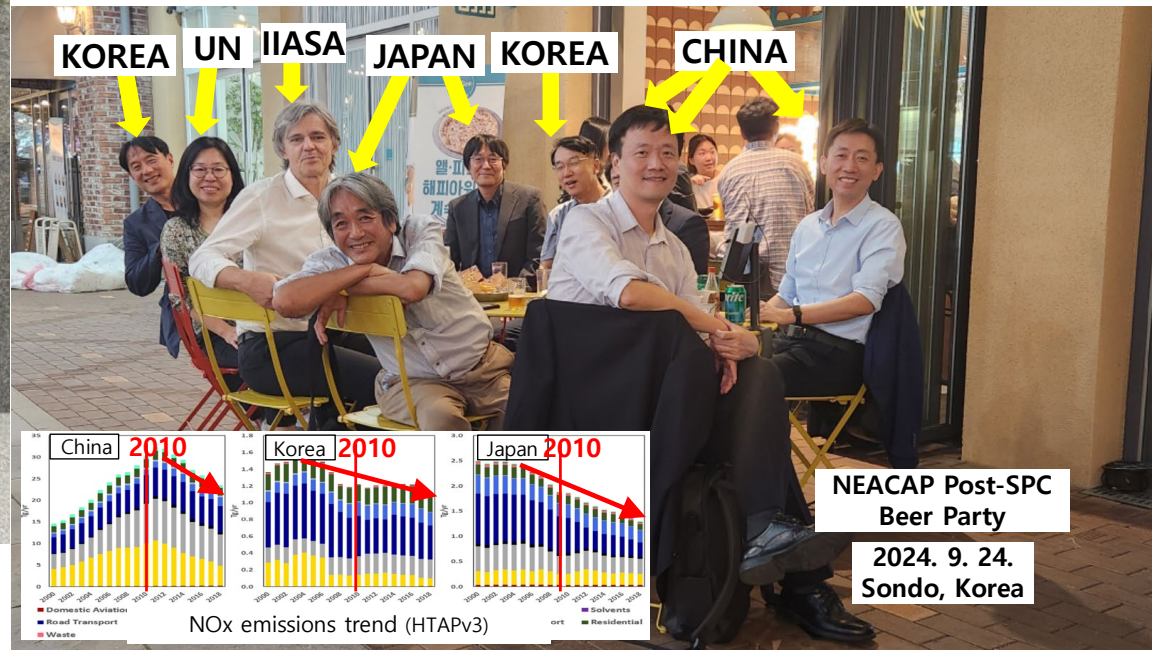
Photo from my 'BlueSky Hotel' room, today morning





A role of science is
to provide valuable, careful information
to policymakers
to help them make well-informed decisions.

- Detlev Helmig



Баярлалаа!

Thank you! **Danke!** Спасибо 谢谢! 감사합니다! ありがとうございます!