Integrated Assessment Modeling on Air pollution and Climate Change

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Contents

- Introduction of the Air pollution modeling with the Integrated Assessment Model used for the Climate Change Study (AIM: Asia Pacific Integrated Assessment Model)
- Some examples of Air Pollution modeling studies along the Integrated Assessment Model framework.
  1. Quantification of Co-benefit of Regional Low Carbon Society Policies on Air Pollution
- Idea on a possible collaborative program
Overview of AIM (1)

AIM (Asia-Pacific Integrated Model) is an integrated assessment model to assess mitigation options to reduce GHG emissions and impact/adaptation to avoid severe climate change damages. The model is extended to assess sustainable development policies together with Asian researchers.

(1) Emission modules ....
• World Economic Model
• Energy Technology Selection Model
• Material Recycle Model  • Industry Model
• Landuse / Landuse Change Model
• Scenario development Model  • Simplified Model

(2) Climate Modules...
• Carbon cycle Model  • Chemical Transport Model
• Global Average Climate Model
• Regional Climate Model

(3) Impact Modules ...
• Water Resource Impact Model
• Agriculture Impact Model
• Potential Vegetation Impact Model
• Health Impact Model  • Economic Impact Model
Overview of AIM (2)

http://www-iam.nies.go.jp/aim/
AIM models for GHG mitigation analyses
MOEJ-S12: Active evaluation of SLCP impacts and seeking the optimal pathway (2014-2018)  
PI: Terry Nakajima

- Reduction of SLCP is easier than that of LLGHG due to their short lifetime, but the effects are very complex.
- Therefore, search for optimum mitigation paths is important for society.
- It is needed to develop an active evaluation system for LLGHG and SLCP mitigation policy, by overarching emission inventory, integrated models, and climate models.

![Diagram](image)

- Emission inventory
- Regional AQ change events: Regional modeling
  - Improving emission inventories through analysis of regional air quality change events

- Emission scenario
- Emission scenario & Optimum mitigation path: Socio-economical & technology model (AIM)
  - Improvement of AIM to reflect the SLCP regional change

- Upscaling the regional mitigation experiences to global
- Global climate impacts: Climate modeling
  - Assessment of regional and global climate/agriculture, and health environment impacts
  - Sea level rise
    - Hu et al (2013)

- Black Carbon (μg m⁻³)
  - Praveen et al (2011)

- SO₂ future scenarios
  - BAU
  - Mitigation
  - Mitigation delayed
  - Ols
Reduction of Short lived Climate Pollutants and Global average temperature

Source: Figure 6.1, UNEP/WMO (2011) Integrated Assessment of BC and tropospheric O3
**SLCP emission in AIM model**

**Goal:** To develop an integrated evaluation system for LLGHG and SLCP mitigation policy, by interconnecting emission inventory, integrated assessment models, and climate models.

- **Theme 1:** Air quality change event analysis
  - Analysis on regional AQ change
  - Development of emission inventory
  - Inversion algorithms of emission estimation

- **Theme 2:** Integrated model and future scenarios
  - Global socio-economic scenarios
  - National & regional emissions scenarios
  - Urban & household emissions AQ assessment

- **Theme 3:** SLCP impacts on climate & environment
  - Impact assessment of aerosols & GHG
  - Assessment of health, agriculture, water cycle, sea level rise

**Integrated Assessment Model (AIM)**

- Improved emission inventory
- SLCP emissions scenarios
- Assessment of activities/policies
- Feedback of impacts

**Chemical transfer model and emission inventory in Asia**

**AIM/Enduse model**

- Socio-economical & emissions scenario

**Climate model, earth system model**

- Climate change impact & adaptation

**Theme 4:** Integrated operation system (Toolkits, data archive)

**Science**
- Model improvement
- Experiment setup
- Database development
- Metric definitions

**Stakeholders**
- Policy makers
- System utilization

**Society**
- Information transmission

**Regional strategy**

- MDG • SDG • Future Earth

**Global strategy**
SSPs (Shared Socioeconomic Pathways) and effect of additional Climate & Air Pollution policy

1. SCLP emission abatement technology: FDG, CM on Agriculture, etc.,
2. Improvement of Fuel Quality
3. Energy saving, Improvement of Energy Efficiency
4. Fuel shift
Overview of AIM/Enduse[Global] and element models
Sample Output from AIM/Enduse[Global] Model

Technological transition in the power sector

By Dr. Akashi et al
Sample Output from AIM/Enduse [Global] Model

CO₂ emissions and contribution of reduction options

By Dr. Akashi et al
Socio-Economic, Emission, Concentration, Impact

The urban and residential emission scenario of LLGHG-SLCP

- Urban activity model
  - Traffic demand model
- Residential Model
  - Household Energy - Service demand model
  - Enduse technology selection model
  - Household fuel scenario

Dynamic optimization Model
- Optimal reduction path search

Cooperation with other teams
- GHG-SLCP Emission scenario (World)
- GHG-SLCP Emission Scenario (Country)
- Enduse Technology selection model (AIM/Enduse)
- Emission Inventory and Future estimation

Feedback

Spatial Down scaling
- Emission Map

Long-range Chemical transport model (WRF/CMAQ)
- Urban scale air pollution model (Roadside and city block model)

Personal exposure model
- Health impact

Analysis of air pollution impact
Detail component of the Air Quality, Impact Model

World/Country Emission Scenario
- World End use Model
  - The traffic model in city
- Residential Energy demand model
  - Enduse Technology Model
- Emission Mesh Data
  - Spatial Allocation Index
  - Diurnal and Seasonal Change
  - ArcGIS
    - Emission Inventory
      - The amount mesh data of discharge
- CMAQ
  - Chemical Transport Model
    - Boundary condition
      - Meteorological data
        - Landuse / topography
          - Re-analysis Met. data / Climate Model data
            - 1990-2010 / 2020, 2030, 2050

Individual exposure and Health impact
- Personal Exposure
- Health impact
- Indoor source emission
- Time use survey
- House structure
  - Air change rate
  - Extraction ratio
  - Penetration rate
- Ecosystem impact
- Spatial distribution of Pollutant
- Outdoor exposure And Intrusion to Indoor

Roadside Model
- Sub-grid scale model
Roadside Model

- Calculation case and mesh size:
  Fine Case: 1km
- Divided a mesh to 3 classes by the distance from road.

\[ C(x) = E_r \cdot f(x) \]

- \( C(x, z) = \frac{Q_L}{(u \sin \theta)^{0.5}} \cdot \frac{A}{x} \cdot \exp \left( -\frac{B z^p}{x} \right) \times W(x : y_1, y_2) \)

\( C_x,y)\): Concentration, \( x \): distance from road, \( z \): height, \( Q_L \): emission intensity, \( u \): wind velocity
\( \theta \) : angle between Road and Wind,
Definition of the buffer area of Roadside Model

In the case of Beijing 1 km mesh case.
In the Urban area, Major contributor is “indoor w/o emission”, this mean source of pollutants is outdoor, and stay duration to indoor is much longer than duration at outdoor.

Still exposure in rural area is higher than urban area due to the high usage of biomass fuel in Kitchen and Heating.
Feedback of Health impact to Socio-Economic Model (1)

Fig. 1 Research Framework.

<table>
<thead>
<tr>
<th>Category</th>
<th>Endpoint PM2.5</th>
<th>Endpoint ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work loss</td>
<td>Work loss day from morbidity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work loss day from cumulative mortality</td>
<td></td>
</tr>
<tr>
<td>Morbidity</td>
<td><strong>Respiratory</strong> hospital admissions</td>
<td><strong>Respiratory</strong> hospital admissions</td>
</tr>
<tr>
<td></td>
<td>Cerebrovascular hospital admission</td>
<td>Lower respiratory symptoms</td>
</tr>
<tr>
<td></td>
<td>Cardiovascular hospital admissions</td>
<td>Bronchodialtor usage</td>
</tr>
<tr>
<td></td>
<td>Chronic bronchitis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asthma attacks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Respiratory symptoms days</td>
<td></td>
</tr>
<tr>
<td>Mortality</td>
<td>All cause</td>
<td>All cause</td>
</tr>
</tbody>
</table>

Socioeconomic /Climate policy | Ref  | 34W  |
---|---|---|
SSP2 | SSP2_ref | SSP2_34W |
SSP3 | SSP3_ref | SSP3_34W |
Feedback of Health impact to Socio-Economic Model (2)
Socio-Economic, Emission, Concentration, Impact

The urban and residential emission scenario of LGHG-SLCP

GHG-SLCP Emission scenario (World)
GHG-SLCP Emission Scenario (Country)
Enduse Technology selection model (AIM/Enduse)

Cooperation with other teams
Emission Inventory and Future estimation

Feedback
Urban activity model
Traffic demand model
Residential Model
Household Energy - Service demand model
Enduse technology selection model
Household fuel scenario

Spatial Down scaling
Emission Map

Long-range Chemical transport model (WRF/CMAQ)
Urban scale air pollution model (Roadside and city block model)

Personal exposure model
Health impact

Dynamic optimization Model
Optimal reduction path search

Analysis of air pollution impact
Importance of Residential Sector

China, CO2 emission
SSP2 Ref + High electrification

China, BC emission
SSP2 Ref + High electrification

India, CO2 emission
SSP2 Ref + High electrification

India, BC emission
SSP2 Ref + High electrification
Lack of attention to Residential Sector

CO2, Residential sector, China

SSP2 Reference CO2 emission by Technology for Residential sector 2010-2050 China

Heating
Lighting (Oil)
Cooking
Hot water

There are no difference between Countermeasure cases for Climate Change

Because, the Climate Policy mainly focus on the Power generation, industrial sector and Transportation sector.
Improvement of Residential sector model

◆ Lack of Future Service demand estimation
  ◆ Because there are large differences in lifestyle between regions, it is difficult to estimate the service demand in the future residential sector.

◆ Lack of Technology Information
  ◆ Bottom-up model carries out technology selection according to economic rationality. However, in addition to the lack of information on the initial cost and running cost of the household equipment, it differs greatly from country by country.

◆ Lack of Emission Factor for air pollutants.
  ◆ The emission factors of air pollutants from household equipment are extremely limited.
Quantification of Co-benefit of Regional Low Carbon Society Policies on Air Pollution

- We focus on the city level co-benefits under the detail Low Carbon Society Scenario and quantified the reduction of air pollutants by each LCS policies on Iskandar Malaysia’s LCS scenarios.

**Target Area**

- Population: 2005 1.8million → 2025 3.0million
- GDP: × 4.0 GHG emission (BaU): × 2.75
- Low Carbon Society Scenario for 2025 have been developed
- Co-benefit of LCS policies on air pollution was considered.
Methodology (1)

1. Development of Low Carbon Society Scenario for 2025 for Iskandar Malaysia

2. Downscaling the emission source to Map (NOx, SO2, CO, PM2.5)
   - Transportation Sector
     - Traffic Demand Analysis Model
     - Downscaling by road network
   - Other Sector
     - Downscaling by population, Landuse and LPS

3. Calculate the yearly average concentration in the region by using WRF/CMAQ.

4. Estimate the premature death by the long-term exposure to PM2.5
AIM models for GHG mitigation analyses
Model Framework of ExSS

- Export
- Import ratio
- Government expenditure
- Labor productivity
- Commuting OD
- Labor participation ratio
- Demographic composition
- Average number of family occupants

Macro-economy and Industry Module
- Output
- Labor demand
  - Wage
- Private consumption
  - Breakdown of consumption
- Floor area per output
- Floor area of commercial buildings

Labo Module
- Average working time
- Income

Time-use and Consumption Module
- Number of workers

Population and Household Number Module
- Population
- Number of household
- Population distribution
- Trip per parson
- Transport distance
- Modal share

Commercial Building Module
- Passenger and freight transport demand

Transport Module
- Energy demand

Energy Demand & GHG Emissions Module
- Main endogenous variables
- Exogenous variables and parameters
- Module
- Flow of endogenous variables
- Input

- Energy service demand generation unit
- Energy efficiency
- Fuel share
- Emission factor
Methodology (2)

Mitigation Options

<table>
<thead>
<tr>
<th>Green Economy</th>
<th>Sub-action</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action 1 Integrated Green Transportation</td>
<td><strong>Integrated Public Transportation</strong></td>
<td><strong>Public transport system improvement</strong></td>
</tr>
<tr>
<td></td>
<td>Introduction of rail-based and water-based public transport</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Efficient/ seamless intermodal transfer (interchange) facilities</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improve B-Singapore, B-KL Connectivity</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Diffusion of Low Carbon Passenger Vehicles</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enhance traffic flow conditions and performance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green Transportation in Rural Areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Green Freight Transportation</strong></td>
<td></td>
</tr>
<tr>
<td>Green Community</td>
<td>Action 6 Low Carbon Lifestyle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Action 7 Community Engagement and Consensus Building**</td>
<td></td>
</tr>
<tr>
<td>Green Environment</td>
<td>Action 8 Walkable, Safe and Livable City Design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Action 9 Smart Urban Growth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Action 10 Green and Blue Infrastructure and Rural Resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Action 11 Sustainable Waste Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Action 12 Clean Air Environment**</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12 Actions</td>
<td>53 Sub-Actions</td>
</tr>
<tr>
<td></td>
<td>96 Measures</td>
<td>300 Programs</td>
</tr>
</tbody>
</table>

d Quantify and Parameterize each Program to Socio-Economic parameters
### LCS scenarios for policy development in IM

#### GHG reductions by Actions

<table>
<thead>
<tr>
<th>Mitigation Options</th>
<th>ktCO₂ Reduction</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Green Economy</strong></td>
<td>6,937</td>
<td>54%</td>
</tr>
<tr>
<td>Action 1 Integrated Green Transportation</td>
<td>1,916</td>
<td>15%</td>
</tr>
<tr>
<td>Action 2 Green Industry</td>
<td>1,094</td>
<td>9%</td>
</tr>
<tr>
<td>Action 3 Low Carbon Urban Governance**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Action 4 Green Building and Construction</td>
<td>1,203</td>
<td>9%</td>
</tr>
<tr>
<td>Action 5 Green Energy System and Renewable Energy</td>
<td>2,725</td>
<td>21%</td>
</tr>
<tr>
<td><strong>Green Community</strong></td>
<td>2,727</td>
<td>21%</td>
</tr>
<tr>
<td>Action 6 Low Carbon Lifestyle</td>
<td>2,727</td>
<td>21%</td>
</tr>
<tr>
<td>Action 7 Community Engagement and Consensus Building**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Green Environment</strong></td>
<td>3,094</td>
<td>25%</td>
</tr>
<tr>
<td>Action 8 Walkable, Safe and Livable City Design</td>
<td>263</td>
<td>2%</td>
</tr>
<tr>
<td>Action 9 Smart Urban Growth</td>
<td>1,214</td>
<td>10%</td>
</tr>
<tr>
<td>Action 10 Green and Blue Infrastructure and Rural Resources</td>
<td>392</td>
<td>3%</td>
</tr>
<tr>
<td>Action 11 Sustainable Waste Management</td>
<td>1,224</td>
<td>10%</td>
</tr>
<tr>
<td>Action 12 Clean Air Environment**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>12,467**</td>
<td>100%</td>
</tr>
</tbody>
</table>

---

#### Estimated GHG reduction by each LCS actions

- **2005**: 11.4 MtCO₂eq
- **2025 BaU**: 31.3 MtCO₂eq
- **2025 CM**: 18.9 MtCO₂eq

**Example 1**

Estimated from ExSS Model
Example 1

Model description (Quantification of Co-benefits)

**Meteorological Model**
- **WRF 3.4.1**
  - NCEP-FNL (1 degree, 6 hours)
  - Noah land-surface model
  - WSM 3-class simple ice scheme

**Chemical Transport Model**
- **CMAQ 5.0.1**
  - Chemistry: SAPRC-99 - AERO5
  - Boundary condition: MOZART4
  - Biogenic Emission: MEGAN
Example 1  Reduction of Regional Air Pollutants Emission

LCS Policies

1: Green Transportation  7: Consensus Building
2: Green Industry  
3: Low Carbon Urban Governance  
4: Green Building and Construction  
5: Green Energy System  
6: Low Carbon Lifestyle  
8: Walkable, Safe and Livable City Design
9: Smart Urban Growth
10: Green and Blue Infrastructure and Rural Resources
11: Sustainable Waste Management
12: Clean Air Environment
Example 1  Methodology: Emission from Road Traffic

Traffic Demand Analysis Model:
STRADA version 4.0 by JICA

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Change of EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Current</td>
<td></td>
</tr>
<tr>
<td>2025 BaU</td>
<td>Proportional to Population growth</td>
<td>Current</td>
</tr>
<tr>
<td>2025 CM1</td>
<td>Bus Rapid Transit</td>
<td></td>
</tr>
<tr>
<td>2025 CM2</td>
<td>Further Public transportation Shift</td>
<td></td>
</tr>
<tr>
<td>2025 CM3</td>
<td>Same as 2025 BaU</td>
<td>Promotion of Low Emission Car</td>
</tr>
<tr>
<td>2025 CM4</td>
<td>Same as 2025 CM1</td>
<td></td>
</tr>
</tbody>
</table>
• In 2025 BaU case, Traffic volume increase with the population growth. And due to the congestion of traffic in central area, traffic volume of Suburb road is significantly increased.
• In 2025 CM2 case, Traffic volume will decrease by the shift to public transportation. Total volume is equivalent to current volume.
• Emission of PM2.5 largely depends on the emission control of public bus system.
Example 1

Improvement of GIS information for downscaling

Population density
3km mesh $\rightarrow$ 0.6 km mesh

Road network

Open Street Map
Example 1

Estimation of Future Population distribution
Regional Air Quality Simulation

Example 1

Domain 1

Domain 2

Domain 3

Calculated PM2.5 Concentration
(8am 2 JAN 2013)
Health impact

Methodology used by the Global Burden of Disease (WHO, 2004)

\[ \Delta RR = \exp(\beta \times \Delta C) \]
\[ \Delta AP_k = (\Delta RR - 1) \div \Delta RR \]
\[ E = \Delta AP \times f \times P \]

where,
- \( \Delta RR \) : Change of Relative Risk
- \( \beta \) : Relative risk coefficient
- \( \Delta C \) : Change of PM\(_{2.5} \) concentration from base state
- \( \Delta AP \) : Change of attributable proportion for health endpoint
- \( E \) : Number of cases of death attributed to air pollution
- \( f \) : all cause mortality rate
### Example 1

**Result (Co-benefits on Health impact)**

#### Results [Whole IM region]

<table>
<thead>
<tr>
<th>Case</th>
<th>N. of Death [person/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>population in 2015 Base conc.</td>
<td>345</td>
</tr>
<tr>
<td>Population in 2025 BaU case conc.</td>
<td>417</td>
</tr>
<tr>
<td>Population in 2025 CM case conc.</td>
<td>254</td>
</tr>
</tbody>
</table>

Reduced premature death (Δ=163) by each actions

- **Low carbon Lifestyle**
  - ΔDeath: 8.0
  - N. of Death: 38.5

- **Walkable & Safety city**
  - N. of Death: 114.7

- **Green Building**
  - N. of Death: 1.5

- **Green Industry**
  - N. of Death: 0.2

- **Green Transportation**
  - N. of Death: 0.2
Concept of IAM for Air Pollutant emission

Source-receptor matrix

Activity → Emission → Concentration → Exposure → Impact → Feedback

- Compact city
- Energy saving
- Zero energy building
- Public transportation
- ...

- FGD/dust collector
- High stacks

No policy action

- Medical system
- ...

- Forecast
- Warning system
- Air cleaner

Economic Model AIM/CGE
Bottom-up Model AIM/Enduse Accounting Model ExSS
Idea on a possible collaborative program


- **Standardization and Sharing of**
  - Activity Database (Driving force of emission)
    - Past, current and Future. National level, Province level, Gridded data.
  - Technology Database (Energy Efficiency and Emission Factor)
    - Abatement Technology, Low emission Technology, etc.,
    - Especially, initial cost and running cost, lifetime, obstacle of diffusion
  - Policy Database
    - Tax and subsidy, Regulation, Urban planning, TDM, etc.,
Thank you very much for your attention