Impacts of Economic Development and Urbanization in South/Southeast ASIA for Estimating Future GHGs Emissions - CH₄ Emissions from Landfill -

Tatsuya HANAOKA

Center for Social and Environmental Systems
National Institute for Environmental Studies
Japan

Asia-Pacific Integrated Model
http://www-iam.nies.go.jp/aim/index.html
**MOEJ-S12: Promotion of climate policies by assessing environmental impacts of SLCP and seeking LLGHG emission pathways (FY2014 – FY2018)**

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

**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
- MDG • SDG • Future Earth
  - CCAC, UNFCC, IPCC, EANET
  - Proposal and assessment of climate and air pollution policies

**Regional strategy**

**Global strategy**
Overview of Key Research Topics

- Urbanization
- Electrification
- Industrialization
- Fuel Energy Consumption
- Electricity Consumption
- Passenger Transport Volume
- Residential Service Demand
- Commercial Service Demand
- CH4, N2O, CO2, PM, BC, SO2, NOx, etc
Research Motivations
- how to achieve emissions pathways of the 2°C target? -

What kinds of SLCP measures can be?
How drastic it should be?

How about air pollutants reductions and their benefits and trade-offs, when achieving 2 degree?

This study aim to seek for balanced emissions scenarios of LLGHGs, SLCPs, air pollutants and evaluate cobenefits and tradeoffs of mitigation measures

If SLCPs reductions are fully implemented by 2030, it reduces global warming between 2010 to 2040 by about 0.4 – 0.5 °C

Remaining cumulative CO₂ emissions (i.e. carbon budgets) staying below 2°C are around 1000 GtCO₂

Remaining around 1000 GtCO₂

Source) UNEP (2011), Figure ES-2

Source) IPCC AR5 Synthesis Report (2015) Figure SPM.5
Short-Lived Climate Pollutants
- How much can we reduce SLCPs? -

**SHORT-LIVED CLIMATE POLLUTANTS**
Near term response to mitigation

<table>
<thead>
<tr>
<th>SUBSTANCE</th>
<th>ANTHROPOGENIC SOURCES</th>
<th>LIFETIME IN ATMOSPHERE</th>
<th>IMPACTS/MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACK CARBON (BC)</td>
<td></td>
<td>DAYS</td>
<td>Local</td>
</tr>
<tr>
<td>METHANE (CH₄)</td>
<td></td>
<td>12 YEARS</td>
<td>Regional</td>
</tr>
<tr>
<td>TROPOSPHERIC OZONE (O₃)</td>
<td></td>
<td>WEEKS</td>
<td>Global</td>
</tr>
<tr>
<td>HYDROFLUOROCARBONS (HFCs)</td>
<td></td>
<td>15 YEARS (WEIGHTED BY USAGE)</td>
<td>Global</td>
</tr>
</tbody>
</table>

Source: Climate and Clean Air Coalition http://www.ccacoalition.org/en/science-resources
Backgrounds
- Sources of CH$_4$ emission from Asia

We have mitigation measures for waste. We can reduce landfill waste. But how?

- Power
- Mining
- Industry
- Transport
- Buildings
- Waste
- Agriculture
- Agriculture waste burning
- Savannah burning etc

Source: EDGER4.2

Socio-economic scenario
Population & Household number
Macro Economic frame Model
GDP & Sector value added

Today's topic

Macro-economic model

Service demand models
Steel Production & Trade Model
Cement Production Model
Transportation Demand Model
Household Lifestyle Model
Municipal Solid Waste Model
Agricultural Prod & Trade model
Fluorocarbon Emission Model

Bottom-up model (i.e. AIM/Enduse)

Energy Resource DB
Coal
Oil
Gas
Nuclear
Hydro
Geothermal
Solar
Wind
Biomass

Energy mining sector
Primary energy
Energy Supply sector
Primary energy
Energy balance

Emissions

Today's topic

Energy Resource DB
Energy mining sector
Energy Supply sector

Efficiency
Technology DB
Energy price
Emission factor
Lifetime
Diffusion rate

Variable
Model
Database
The 2006 IPCC Guidelines for National Greenhouse Gas Inventories

- **4A Solid Waste Disposal**
  - CH$_4$ emissions from landfilled municipal, industrial and other solid waste are reported.
  - Generally, this category is the largest source of GHG emissions in the Waste Sector.

- **4B Biological Treatment of Solid Waste**
  - CH$_4$ and N$_2$O emissions from Composting and Anaerobic digestion of organic waste are reported.

- **4C Incineration and Open Burning of Waste**
  - CO$_2$ and CH$_4$ and N$_2$O emissions from waste incineration are reported. GHG emissions from incineration with energy recovery are reported in the Energy Sector.

- **4D Wastewater Treatment and Discharge**
  - CH$_4$ and N$_2$O emissions from the wastewater treatment and discharge are reported.

- **4E Other**
In Indonesia and India, methodology of CH$_4$ emissions from industrial wastewater need to be carefully investigated whether emissions are over-estimated.
# GHG Emissions from Waste Sector from Asian Countries

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill (CH₄)</td>
<td>2,928</td>
<td>46,284</td>
<td>10,252</td>
<td>24,409</td>
<td>4,864</td>
<td>5,005</td>
</tr>
<tr>
<td>Industrial waste water (CH₄)</td>
<td>103</td>
<td>25,620</td>
<td>23,163</td>
<td>124,673</td>
<td>1,902</td>
<td>1,617</td>
</tr>
<tr>
<td>Domestic waste water (CH₄)</td>
<td>1,361</td>
<td>8,400</td>
<td>15,036</td>
<td>10,298</td>
<td>1,504</td>
<td>6,827</td>
</tr>
<tr>
<td>Domestic waste water (N₂O)</td>
<td>1,175</td>
<td>28,830</td>
<td>4,101</td>
<td>2,366</td>
<td>1,023</td>
<td>1,838</td>
</tr>
<tr>
<td>Incineration - Open burning (CO₂, CH₄, N₂O)</td>
<td>28,068</td>
<td>2,658</td>
<td>NE</td>
<td>4,886</td>
<td>23</td>
<td>65</td>
</tr>
<tr>
<td>Others (Compost etc)</td>
<td>826</td>
<td>0</td>
<td>---</td>
<td>199</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>34,460</td>
<td>111,792</td>
<td>52,552</td>
<td>166,831</td>
<td>9,316</td>
<td>15,352</td>
</tr>
</tbody>
</table>

Unit: ktCO₂(CO₂eq)

※1: N2O emission from domestic sewage includes industrial waste water
※2: Solid waste includes industrial solid waste in Japan and Viet Nam. Solid waste in China, India, Indonesia, Thailand are supposed not to include industrial solid waste.
Methodology in the IPCC Guideline
- how to estimate CH$_4$ from solid waste in landfill -

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories

\[ CH_4 \text{ Emissions} = \left[ \sum_x CH_4 \text{ generated}_{x,T} - R_T \right] \cdot (1 - OX_T) \]

\[ CH_4 \text{ generated potential} = W \cdot DOC \cdot DOC_f \cdot MCF \cdot F \cdot (16 / 12) \]

Where

- $T$ : inventory year,
- $x$ : waste category or type/material,
- $R_T$ : recovered CH$_4$ in year $T$,
- $OX_T$ : oxidation factor in year $T$,
- $W$ : mass of waste deposited,
- $DOC$ : degradable organic carbon in year of deposition,
- $DOC_f$ : fraction of DOC that can decompose,
- $MCF$ : CH$_4$ correction factor for aerobic decomposition in the year of deposition,
- $F$ : fraction of CH$_4$ in generated landfill gas.

How to estimate MSW generation is one of keys for the future GHG emissions scenarios.
Research Questions and Methodologies

[ Research question 1 ]

What kinds of socio-economic variables can explain the historical trends of MSW generation per capita?

① Urbanization ratio
② Energy consumption per capita
③ GDP per capita
④ Income per capita

Note)
We need to choose the type of socio-economic variables by considering data availability.
Research Questions and Methodologies

[Research question 2 ]

- What kinds of equations can be applied, in order to explain MSW generations increase?
- If the linear regression is used for estimating MSW generations, it means that generated MSW amounts will keep increasing as explanatory variables increase. But, after reaching a certain level, will it be saturated and/or declined?

Single linear approximation \[ Y = aX + b \]
Logarithmic approximation \[ Y = a \ln(X) + b \]
Quadratic approximation \[ Y = aX^2 + bX + Z \]  \( \rightarrow \) Environmental Kuznets curve

Where

- \( Y \) : MSW generation per capita,
- \( X \) : Socio-economic variables
- \( a, b \) : constant value
- \( Z \) : intercept coefficient.
Historical Municipal Solid Waste (MSW) Generation - China: rapid growing and urbanizing country -

Is there correlation between “provincial GDP per capita” and “provincial MSW generated per capita”, to comprehend features of urbanization?

- Large provinces have linear correlations between GDP per capita and MSW generated per capita in each provinces.
- But difficult to see correlations among provinces. Size and growth rate of MSW per capita are different in large provinces.

- If data in the whole China is compared with provincial data, its characteristic is different because of provincial diversities.
- No superior correlations between linear or logarithm functions, in China’s data. Thus it is better to investigate features including data in other countries, too.

Source) provincial data from 2003 to 2012 in Chinese Statistical Yearbook
Verification of Research Questions
- Correlation with energy use and urbanization -

[ Question ]
The more energy use per capita increase, the more MSW per capita are generated?

Answer: There is a weak correlation. (maybe because energy consumption data includes industries as well as residential?)

![Graph showing correlation between MSW generated per capita and energy use per capita]

\[ y = 31.612x + 368.11 \]
\[ R^2 = 0.1271 \]

[ Question ]
The more urbanization increase, the more MSW per capita are generated?

Answer: There is a weak correlation. (because urban ratio may be one element but not a major for waste generation?)

![Graph showing correlation between MSW generated per capita and urban population ratio]

\[ y = 4.1215x + 185.95 \]
\[ R^2 = 0.1481 \]

Source: Panel data include Japan, China, Thailand, USA, EU27
Verification of Research Questions - Correlation with GDP per capita and income per capita -

The more GDP per capita increase, the more MSW per capita are generated? The more income per capita increase, the more MSW per capita are generated?

Answer:

- Coefficient of determinations are almost similar between these two cases, and it can be reasonable to use GDP per capita as an explanatory variable.
- However, $R^2$ is not high enough, thus it is necessary to check outliers carefully and also to include more reliable data especially in lower-income countries.

Source: Panel data include Japan, China, Thailand, USA, EU27
Verification of Research Questions - Correlation with GDP per capita -

- $R^2$ become increased and reliable if data in the lower-income level is added.
- However, it is necessary to carefully discuss methodologies when GDP per capita reaches the level beyond 5000 US$ per capita, because the increasing trends are different, which trends developing countries will follow.

Source: Panel data include Japan, China, Thailand, USA, EU27, China provincials
Future MSW Generation per capita
- Example in Asian Developing Countries -

- MSW generated per capita will increase as GDP per capita increase in all countries.

- Historical
- Asian-style trend equation function
- Developed countries averaged trend equation function
- Western-style trend equation function
Future MSW Generation
- Example in Asian Developing Countries -

- MSW generated amount = MSW generated per capita × population
Landfill ratios are set at 97%, 70%, 80% and 60% in China, India, Thailand, Viet Nam respectively based on national specific values and the IPCC guideline default values.
Parameters such as waste compositions, degradable organic carbon, aerobic decomposition, etc, are set at based on national specific values and the IPCC guideline default values.
Effects of Reducing Landfill and Introduce Incineration - Example in Asian Developing Countries -

- Considering a scenario if the whole Asia countries take waste policy to cut landfill ratio by half by 2030 and to increase incineration.
- After 2030, keep the same landfill ratio as same as the 2030 level.

- Reduction of landfill can reduce \( \text{CH}_4 \) emission largely
- However, if the same landfill ratio continues after 2030, \( \text{CH}_4 \) emission from landfill will increase again due to waste generation growth. Thus necessary to keep accelerating landfill reduction or recovering \( \text{CH}_4 \) from landfill, to peak out \( \text{CH}_4 \) emission from landfill.
ご清聴ありがとうございました

Timing is important!

Thank you for your attention

Asia-Pacific Integrated Model
http://www-iam.nies.go.jp/aim/index.html
This study applied three different equation functions to the three different concepts of socio-economic scenarios.

Western-style trend equation function

Developed countries averaged trend equation function

Asian-style trend equation function

Details quantitative data and qualitative stories:
https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about
Population and GDP in Asia in SSP Scenarios

Characteristics of GDP per capita will effect on MSW per capita are generated.