Waste Management and Recycling:
Climate Impacts of End-of-Life Treatment

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900 000 000 - 1 250 000 000 tons/year

The estimated global generation of post-consumer waste, around the year 2000.

Waste data is scarce and often of low quality.
Many “rough estimates” and old data

Solid waste treatment is estimated to generate 700-820 MtCO2-eq annually. This equates to around 3% of total GHG emissions.
## Per capita waste generation

<table>
<thead>
<tr>
<th>Income Level</th>
<th>Minimum, Kg/year</th>
<th>Maximum, Kg/year</th>
<th>Average, Kg/year</th>
<th>Average, Kg/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-income</td>
<td>490</td>
<td>609</td>
<td>551</td>
<td>1.5</td>
</tr>
<tr>
<td>Middle-income</td>
<td>246</td>
<td>529</td>
<td>347</td>
<td>0.96</td>
</tr>
<tr>
<td>Low-income</td>
<td>167</td>
<td>420</td>
<td>243</td>
<td>0.67</td>
</tr>
</tbody>
</table>

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*Solid Waste Management in the World’s Cities*
# Average waste composition

<table>
<thead>
<tr>
<th>Income Level</th>
<th>Paper</th>
<th>Glass</th>
<th>Metal</th>
<th>Plastic</th>
<th>Organic</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-income</td>
<td>24%</td>
<td>6%</td>
<td>5%</td>
<td>11%</td>
<td>29%</td>
<td>26%</td>
</tr>
<tr>
<td>Middle-income</td>
<td>11%</td>
<td>4%</td>
<td>4%</td>
<td>12%</td>
<td>54%</td>
<td>15%</td>
</tr>
<tr>
<td>Low-income</td>
<td>7%</td>
<td>2%</td>
<td>1%</td>
<td>7%</td>
<td>63%</td>
<td>18%</td>
</tr>
<tr>
<td>Low-income, excluding outliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>73%</td>
<td>9%</td>
</tr>
</tbody>
</table>

UNHABITAT 2010
## Waste treatment technologies

<table>
<thead>
<tr>
<th></th>
<th>Advanced incineration</th>
<th>Advanced landfill</th>
<th>Simple landfill</th>
<th>Open dumping, open burning. Mostly illegal</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-income</td>
<td>25%</td>
<td>75%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Middle-income</td>
<td>5%</td>
<td>66%</td>
<td>26%</td>
<td>3%</td>
</tr>
<tr>
<td>Low-income</td>
<td>0%</td>
<td>27%</td>
<td>37%</td>
<td>36%</td>
</tr>
</tbody>
</table>

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What are the main sources of GHG emissions from the waste sector?(1)

• Emissions from the waste itself
  – Methane (CH₄)  **The largest source**
    • From anaerobic decomposition of organic waste in landfills and waste dumps
  – Carbon dioxide (CO₂)
    • From incineration or open burning of waste containing fossil carbon such as plastics

NB! **Methane** has a **GWP of 25**, over a 100 year period.
- Each ton of methane is harming the climate as much as 25 tons of CO2.
What are the main sources of GHG emissions from the waste sector?(2)

• Emissions from waste handling
  – Waste collection and transportation (fossil fuels used in vehicles)
  – Landfill operation, waste compaction etc.
  – Incineration.
    • In developing countries waste has low calorific value and contains lots of water. Fossil fuels often need to be added!
Sanitary landfill

http://earth911.com
Projection of CH4 emissions from landfills

Monni et al. 2006

Non-OECD: More than 5 times increase in less than 40 years
Methane pathways in a sanitary landfill

\[
\text{Simplified Landfill Methane Mass Balance}
\]

\[
\text{Methane (CH}_4\text{) produced (mass/time)} = \sum (\text{CH}_4\text{ recovered} + \text{CH}_4\text{ emitted} + \text{CH}_4\text{ oxidized})
\]

IPCC 4AR 2007
Gas collection efficiency

<table>
<thead>
<tr>
<th>Landfill category</th>
<th>Minimum $C_e$</th>
<th>Maximum $C_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open dump</td>
<td>20 - 30</td>
<td>50 - 60</td>
</tr>
<tr>
<td>Controlled dump</td>
<td>40 - 50</td>
<td>60 - 70</td>
</tr>
<tr>
<td>Sanitary landfill</td>
<td>60 - 70</td>
<td>70 - 90</td>
</tr>
</tbody>
</table>

- Even with gas collection, quite a large amount of methane may be emitted.
- Landfill disposal is problematic from a climate perspective.

UNESCAP 2007
The emission of GHGs from a landfill is difficult to measure and to model

- Waste composition
- Waste amount
- Temperature
- Compaction
- Depth
- Precipitation
- Cover layer
- Drainage system
- pH
- Presence of pollutants
- Microbial activity
- Etc.
Trends in developing countries

• Many municipalities in developing countries are trying to improve waste management
  – Smelly and ugly
  – Insects and pests
  – Pollution of soil, water and air
  – Health hazard

• Action taken
  – Increased collection
  – Stop to open burning
  – Upgrading of disposal sites
Improved waste treatment is leading to increasing GHG emissions!

<table>
<thead>
<tr>
<th>Level of development</th>
<th>Disposal method</th>
<th>Climate impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Open dumping, Shallow, uncompacted dump</td>
<td>Low</td>
</tr>
<tr>
<td>Medium</td>
<td>Engineered landfill, Deep, partly compacted, simple cover, no effective gas recovery</td>
<td>HIGH</td>
</tr>
<tr>
<td>High</td>
<td>Sanitary landfill, proper cover, effective gas recovery</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
What are the alternatives to landfills?

- Composting
  - Aerobic treatment, partial degradation of the organic matter
  - Generates mainly CO2
  - Low-tech, low-cost
  - Job creation
  - Can generate soil improver
Successful composting requires

• Good source separation
  – Public awareness

• Adapted technology
  – Low cost
  – Easy operation and maintenance

• Market for the product
Anaerobic digestion also has potential

- Energy generation => climate benefit and potential income
- Waste => Methane => Energy+CO$_2$
- Rest-product can be used for soil improvement

However,...

- More advanced technology than composting
- Sensitive to changes in waste composition
- Gas leakage can be a problem
Why is incineration not common in developing countries?

- High investment cost
- Risk for dioxin formation
  - Expensive equipment and monitoring
  - Public opposition
- Low calorific value and high humidity
  - Fossil fuels need to be added
    - Extra costs
    - GHG emissions
SYSTEMS PERSPECTIVE

GHG Emissions

Extraction of natural resources
Processing
Energy conversion

Consumption

Materials
Energy
Waste

Recycled materials
Recovered energy
Recycling
Incineration
Landfill

GHG Emissions

GHG Emissions
In what other ways can the waste sector influence GHG emissions?

• Materials recycling can reduce the need for extraction and processing of new natural resources.
  – GHG emissions from these processes can thus be reduced.

• Energy recovery (and biogas) can reduce the need for fossil fuels

• Composting can return nutrients and humus to soil
  – The need for fertilizers can be reduced
    • Production of N-fertilizer generates large GHG emissions
    • Application of N-fertilizer can increase emissions of N2O
The importance of recycling: the case of the UK

- The UK’s current recycling of paper/cardboard, glass, plastics, aluminium and steel saves between 10-15 MtCO2-eq per year.
- This is equivalent to about 10% of the annual CO2 emissions from the transport sector, and equates to taking 3.5 million cars off UK roads.
Thank you for your attention
Methane is responsible for the largest climate impact

CO2 from non-fossil sources are not included in GHG inventories.

Carbon flows for post-consumer waste

landfill

incineration

composting

CH₄

(CO₂)

(CO₂)

CO₂ fossil C

Gaseous C emissions

Methane is responsible for the largest climate impact
Carbon storage

Treatment options differ also with respect to how much carbon is stored without being released to the atmosphere.
A. Developed countries
Generation and treatment of municipal waste in Japan
Waste incinerator in Japan

• Advanced incinerators can recover the energy from organic and plastic waste.
• However, currently many Japanese incinerators lack such equipment.
Landfill of Municipal waste in the EU
Systems for recovery of landfill gas

Climate benefit

CH4 -> CO2

and

Replacement of fossil fuels
Trends in developed countries

- Europe
  - Incineration, some energy recovery
  - Pretreatment + Landfill disposal
  - (Composting)

- USA
  - Landfill disposal, some gas recovery

- Japan
  - Incineration, mostly without energy recovery
B. Developing countries
Waste generation and composition in developing Asian countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Solid waste generation (million ton/yr)</th>
<th>Waste generation per urban capita (kg/day)</th>
<th>Waste composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Food</td>
</tr>
<tr>
<td>China</td>
<td>120</td>
<td>1.15</td>
<td>45-55</td>
</tr>
<tr>
<td>India</td>
<td>42</td>
<td>0.4</td>
<td>40</td>
</tr>
<tr>
<td>Indonesia</td>
<td>22.5</td>
<td>0.76</td>
<td>74</td>
</tr>
<tr>
<td>Thailand</td>
<td>14.7</td>
<td>1.1</td>
<td>64</td>
</tr>
<tr>
<td>Viet Nam</td>
<td>12.8</td>
<td>0.4</td>
<td>55-65</td>
</tr>
<tr>
<td>Philippines</td>
<td>11</td>
<td>0.5</td>
<td>45</td>
</tr>
<tr>
<td>Malaysia</td>
<td>8.7</td>
<td>0.9</td>
<td>49</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>4.87</td>
<td>0.41</td>
<td>68</td>
</tr>
<tr>
<td>Cambodia</td>
<td>no data</td>
<td>0.34</td>
<td>66</td>
</tr>
<tr>
<td>Laos</td>
<td>no data</td>
<td>0.75</td>
<td>60</td>
</tr>
</tbody>
</table>

Sources: aRissanen and Naarajärvi, 2004; bKurian, 2007; cToxic Link, 2002; dBalifokus et al., 2006; eZurbrugg, 2002; fPCD, 2009; gIBRD, 1999; hWorld Bank, 2004a; iHanoi University of Science, 2004; jWorld Bank, 2004b; kAguinaldo, 2008; World Bank, 2001; lJICA, 2006; mLee and Hanipiah, 2009; nDOE et al., 2004; oWaste Concern, 2005; pMaclaren, 2005; qKeodalavong, 2007.
Waste treatment in developing Asia
3 Basic strategies

**Strategy 1:** Reduce waste generation

“Producers” of organic waste
- Households
- Shops and markets
- Institutions
- Others

- Landfill -> anaerobic decomposition
- Alternative treatment -> controlled decomposition
- Inert or stabilised organic matter

- Landfill gas including CH₄
- Gas treatment
  -> oxidizing layer
  -> gas collection and burning
- Landfill disposal or beneficial use

**Strategy 2:** Decompose organic matter aerobically so that CH₄ emissions are avoided, or anaerobically in a closed tank and collect the CH₄

**Strategy 3:** Oxidise CH₄ generated in landfill
Treatment options for municipal organic waste

Note: MBT stands for mechanical-biological treatment.
Benefits of composting

• Potential income for low-income groups
• Clean and green neighbourhoods
• Reduced costs for waste collection and disposal
• Soil improvement (nutrients and soil structure)
• Avoided methane emissions
• Reduced need for fertilizers (additional climate benefit!)
• Carbon storage (also a climate benefit!)
## Global Warming Potential (GWP) of waste-related gases

<table>
<thead>
<tr>
<th>GWP values from 2007 IPCC AR4</th>
<th>GWP time horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 years</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>72</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>289</td>
</tr>
</tbody>
</table>

However, recent research indicates that the warming potential of **methane is underestimated**, the 100 years GWP might actually be 10-40% higher than shown in the table.

## Recognition of the waste sector and the 3Rs in Climate Change Strategy documents of Asian developing countries

<table>
<thead>
<tr>
<th>Country</th>
<th>National climate change policy</th>
<th>Indication of the waste sector</th>
<th>3Rs approach to climate change included</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>2007</td>
<td>Yes</td>
<td>Reduce, Recovery, Utilization</td>
</tr>
<tr>
<td>India</td>
<td>2007</td>
<td>Yes</td>
<td>Recycling</td>
</tr>
<tr>
<td>Indonesia</td>
<td>2007</td>
<td>Yes</td>
<td>5Rs for industry &amp; 3Rs for domestic waste</td>
</tr>
<tr>
<td>Thailand</td>
<td>2008</td>
<td>Yes</td>
<td>3Rs</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>2008</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Cambodia</td>
<td>2000</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Philippines</td>
<td>1999</td>
<td>One word</td>
<td>No</td>
</tr>
<tr>
<td>Malaysia</td>
<td>2000</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Lao</td>
<td>2002</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Viet Nam</td>
<td>2003</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Recycling of other waste fractions
Product reuse and materials recycling have upstream climate benefits.
Climate benefits of paper recycling

Comparison of 13 LCA studies

- Newsprint, newspapers, magazines
- Mixed paper, graphic paper, office paper
- Corrugated board and other cardboard
Recycling is *not always* good for the climate

Comparison of 30 LCA studies

Cleaning with hot water and/or cleaning water becomes very high in COD.
Recycling in developing countries has many social and environmental problems.

To improve recycling in developing countries is an urgent and important challenge.
Final points

• Need to use a life-cycle perspective to evaluate pros and cons of treatment options,
• The importance of waste and recycling for CC mitigation is likely to be underestimated,
• Local conditions can have large influence – general recommendations should be treated with caution,
• Scarcity of reliable data is an obstacle to improved waste management,
• The social dimension of waste treatment and recycling is very important, especially in developing countries,
• Proper separation at source -> more options for climate-friendly treatment are possible