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

	Minimum, Kg/year	Maximum, Kg/year	Average, Kg/year	Average, Kg/day
High-income	**490**	**609**	551	**1.5**
Middle-income	**246**	**529**	347	**0.96**
Low-income	**167**	**420**	243	**0.67**

UNHABITAT 2010
Solid Waste Management in the World's Cities


Injekt 10

Average waste composition

	paper	glass	metal	plastic	organic	other
High-income	24%	6%	5%	11%	29%	26%
Middle-income	11%	4%	4%	12%	54%	15%
Low-income	7%	2%	1%	7%	63%	18%
Low-income, excluding outliers					73%	9%

UNHABITAT 2010

Waste treatment technologies

	Advanced incineration	Advanced landfill	Simple landfill	Open dumping, open burning. Mostly illegal
High-income	25%	75%	0%	0%
Middle-income	5%	66%	26%	3%
Low-income	0%	27%	37%	36%

UNHABITAT 2010

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

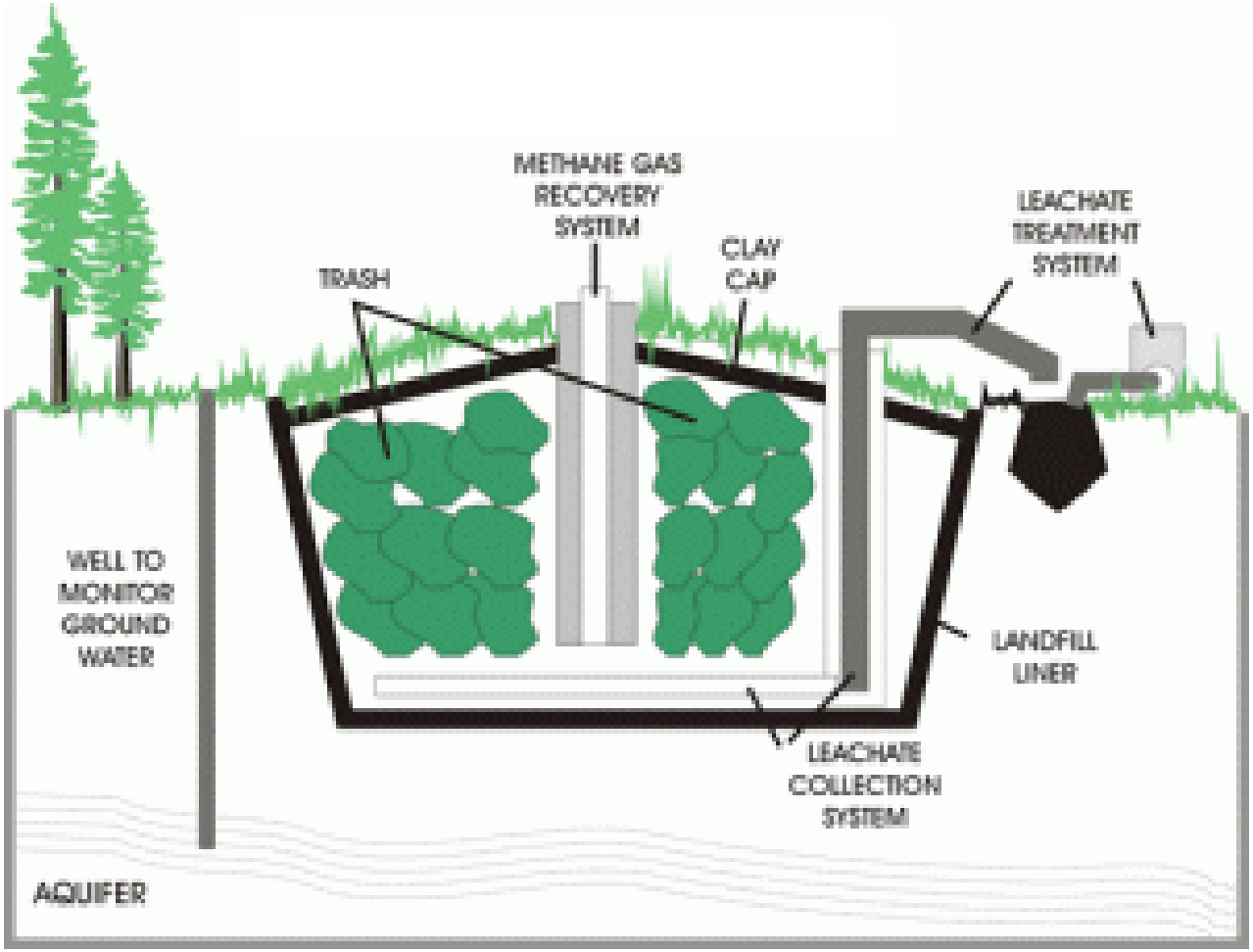
- **Emissions from the waste itself**
  - Methane (CH_4) **The largest source**
    - From anaerobic decomposition of organic waste in landfills and waste dumps
  - Carbon dioxide (CO_2)
    - From incineration or open burning of waste containing fossil carbon such as plastics

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)

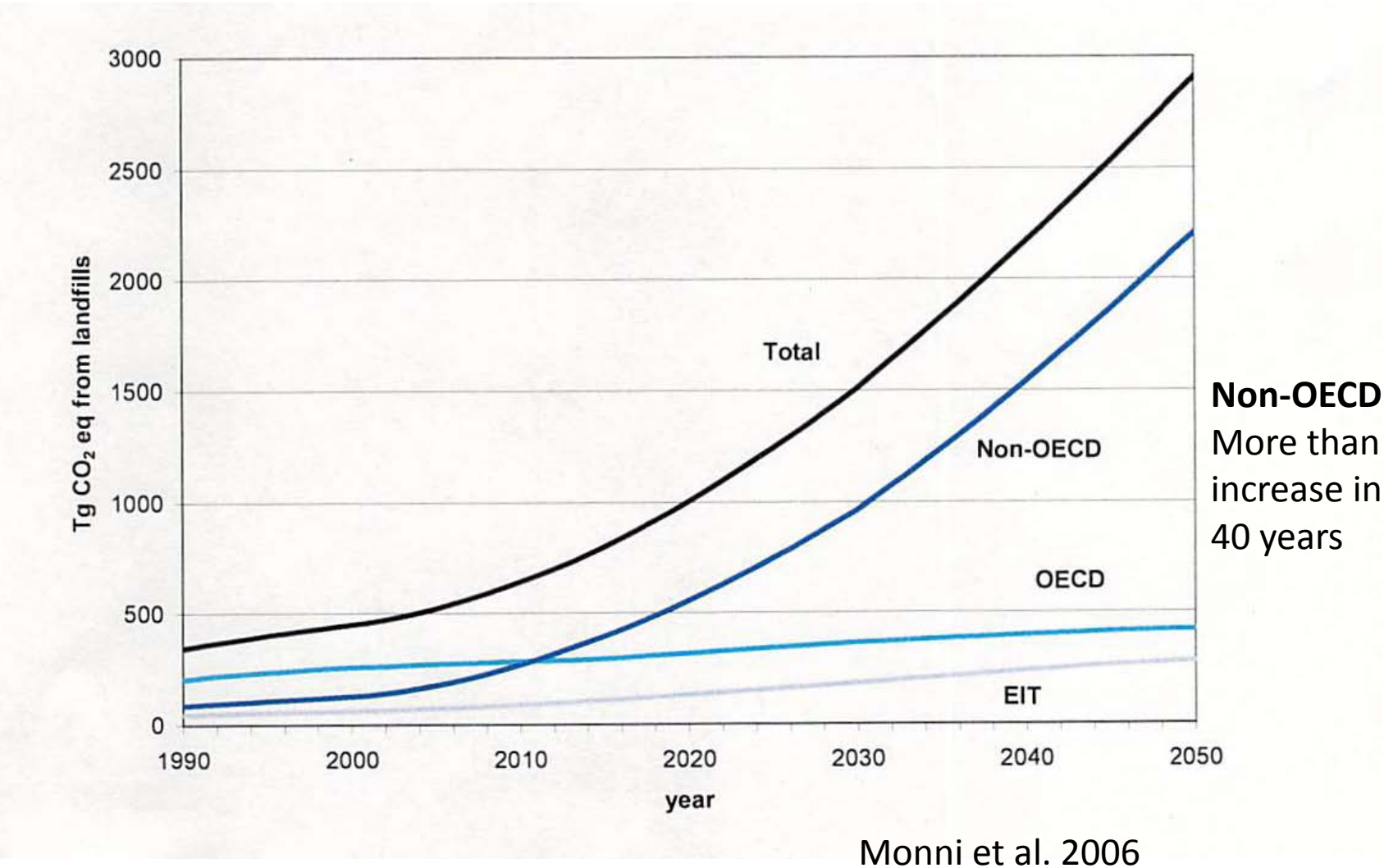
- **Emissions from waste handling**
  - Waste collection and transportation (fossil fuels used in vehicles)
  - Landfill operation, waste compaction etc.
  - Incineration.
    - In developing countries waste has low calorific value and contains lots of water. Fossil fuels often need to be added!

Sanitary landfill



http://earth911.com

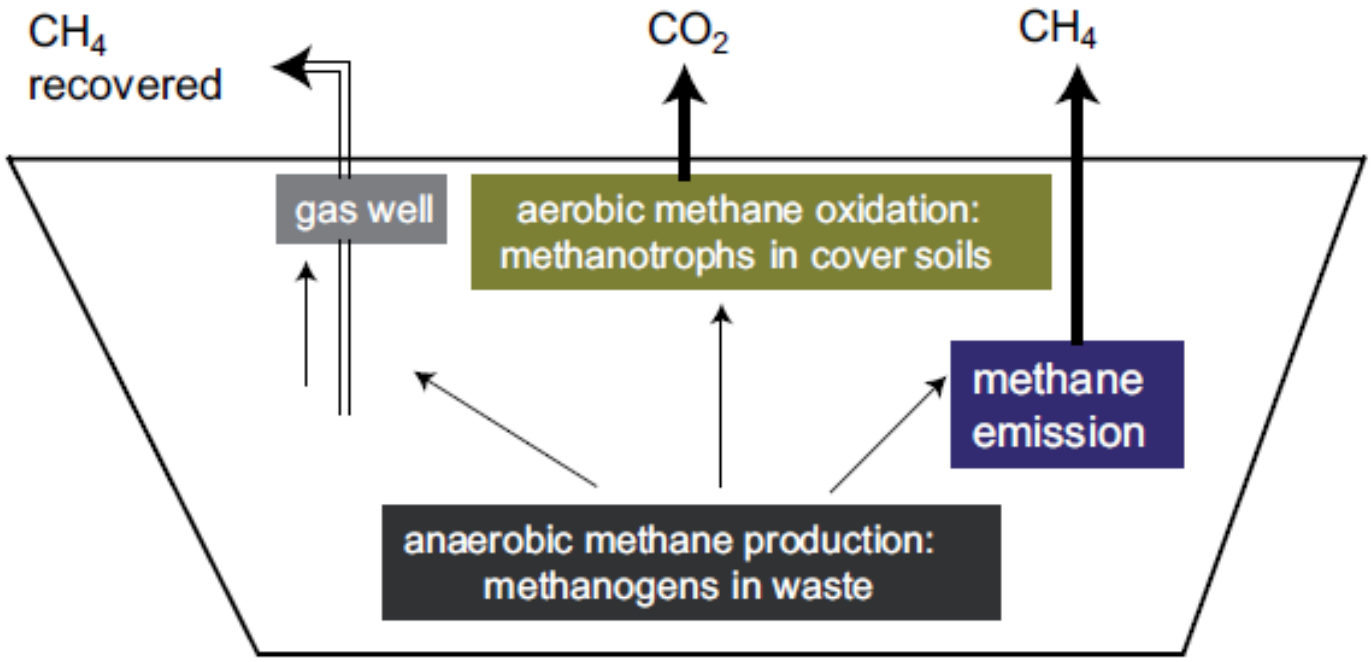
Projection of CH4 emissions from landfills



Non-OECD:
More than 5 times increase in less than 40 years

Monni et al. 2006

Methane pathways in a sanitary landfill



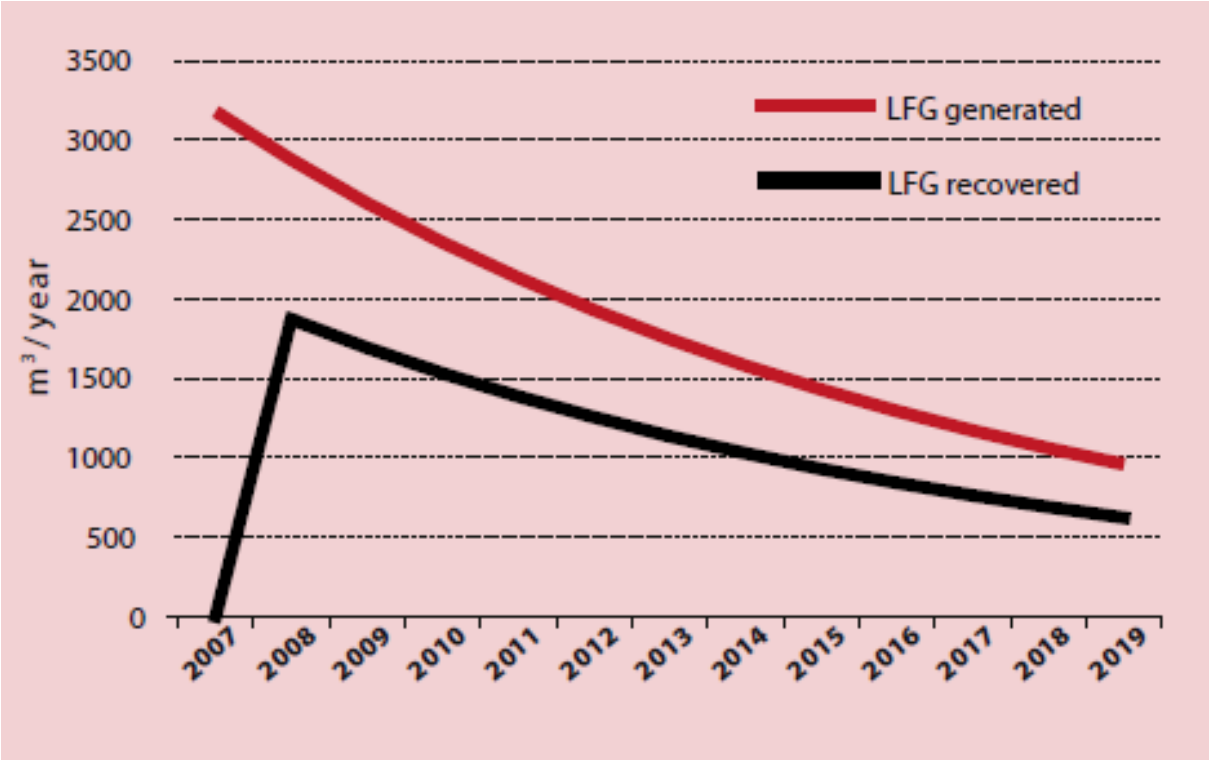
Simplified Landfill Methane Mass Balance

Methane (CH_4) produced (mass/time) = Σ(CH_4 recovered + CH_4 emitted + CH_4 oxidized)

IPCC 4AR 2007

Gas collection efficiency

Landfill category	Minimum C_e	Maximum C_e
Open dump	20 - 30	50 - 60
Controlled dump	40 - 50	60 - 70
Sanitary landfill	60 - 70	70 - 90



UNESCAP 2007

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

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.

Closed landfill in the UK

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!

Level of development	Disposal method	Climate impact
Low	Open dumping Shallow, uncompacted dump	Low
Medium	Engineered landfill Deep, partly compacted, simple cover, no effective gas recovery	HIGH
High	Sanitary landfill, proper cover, effective gas recovery	Moderate

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


6

Successful composting requires

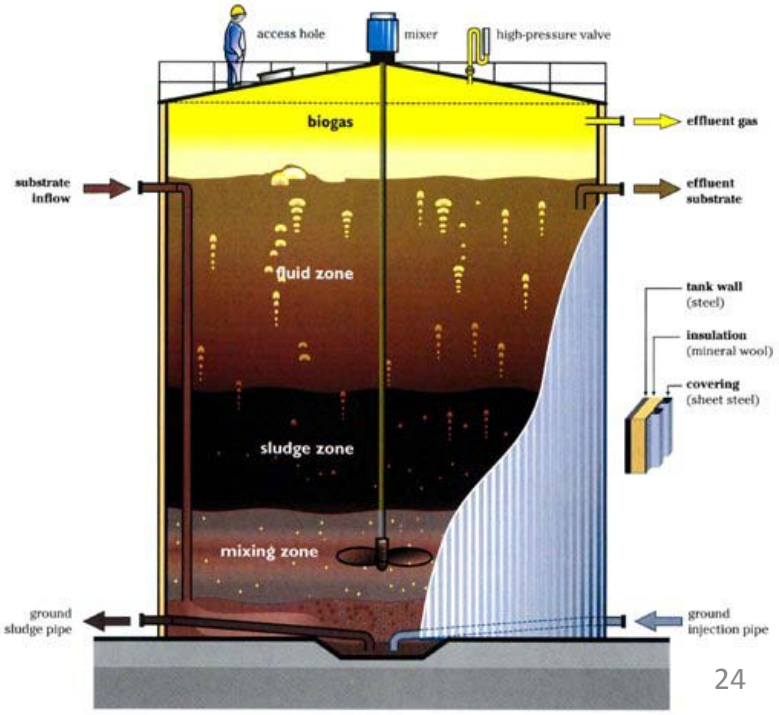
- Good source separation
  - Public awareness
- Adapted technology
  - Low cost
  - Easy operation and maintenance
- Market for the product

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,…

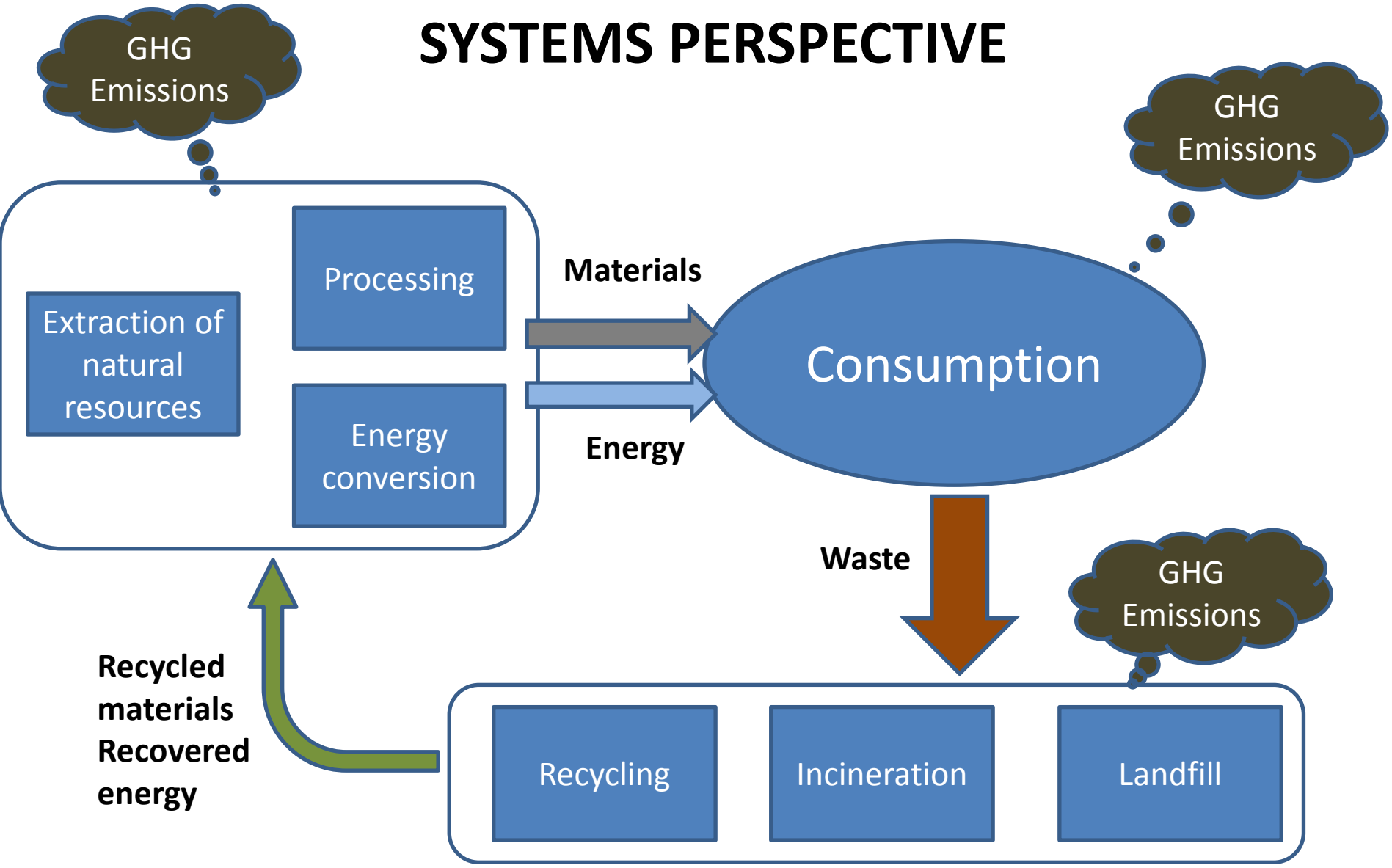
- More advanced technology than composting
- Sensitive to changes in waste composition
- Gas leakage can be a problem



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



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

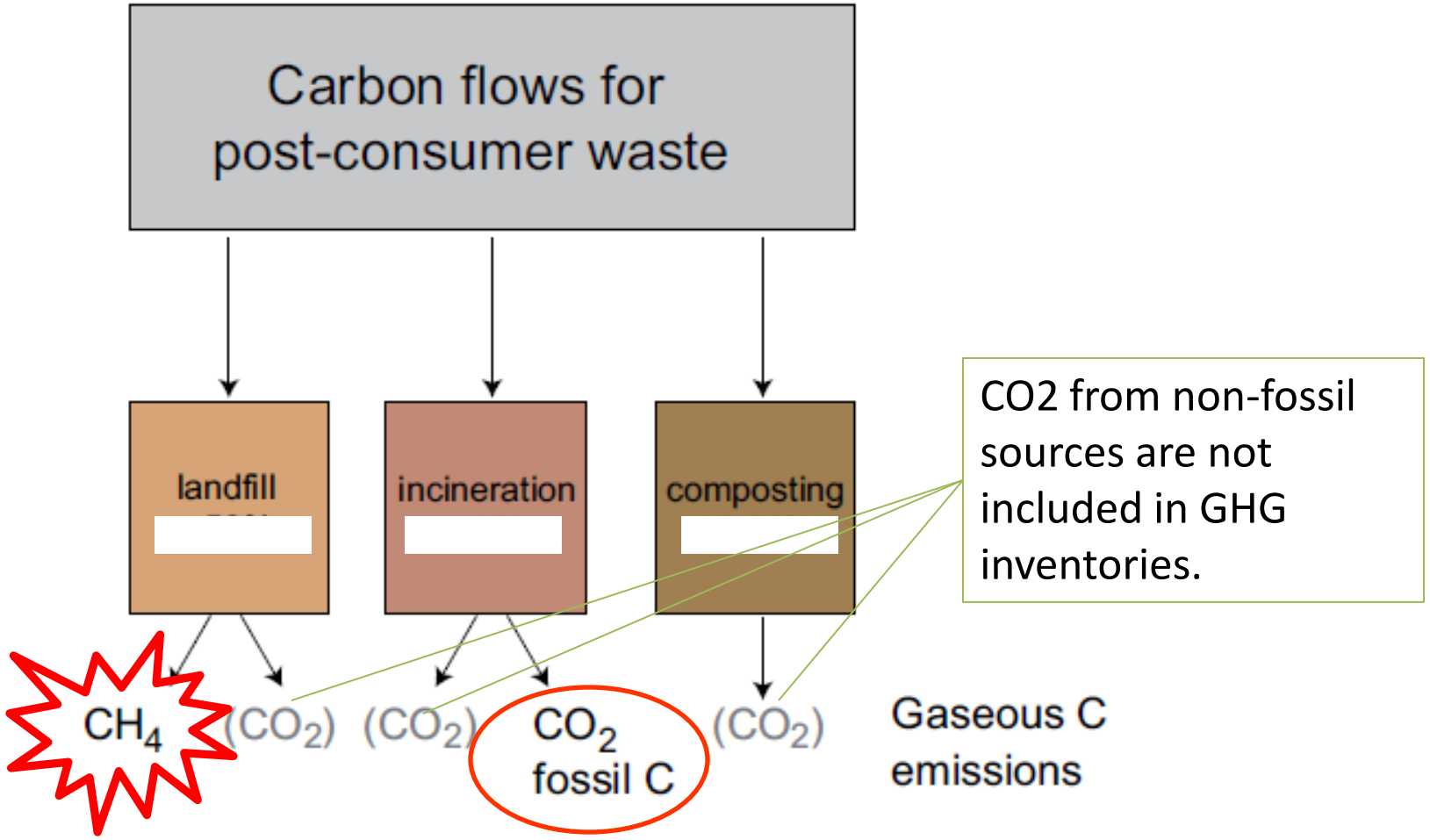
- Materials recycling can reduce the need for extraction and processing of new natural resources.
  - GHG emissions from these processes can thus be reduced.
- Energy recovery (and biogas) can reduce the need for fossil fuels
- Composting can return nutrients and humus to soil
  - The need for fertilizers 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.

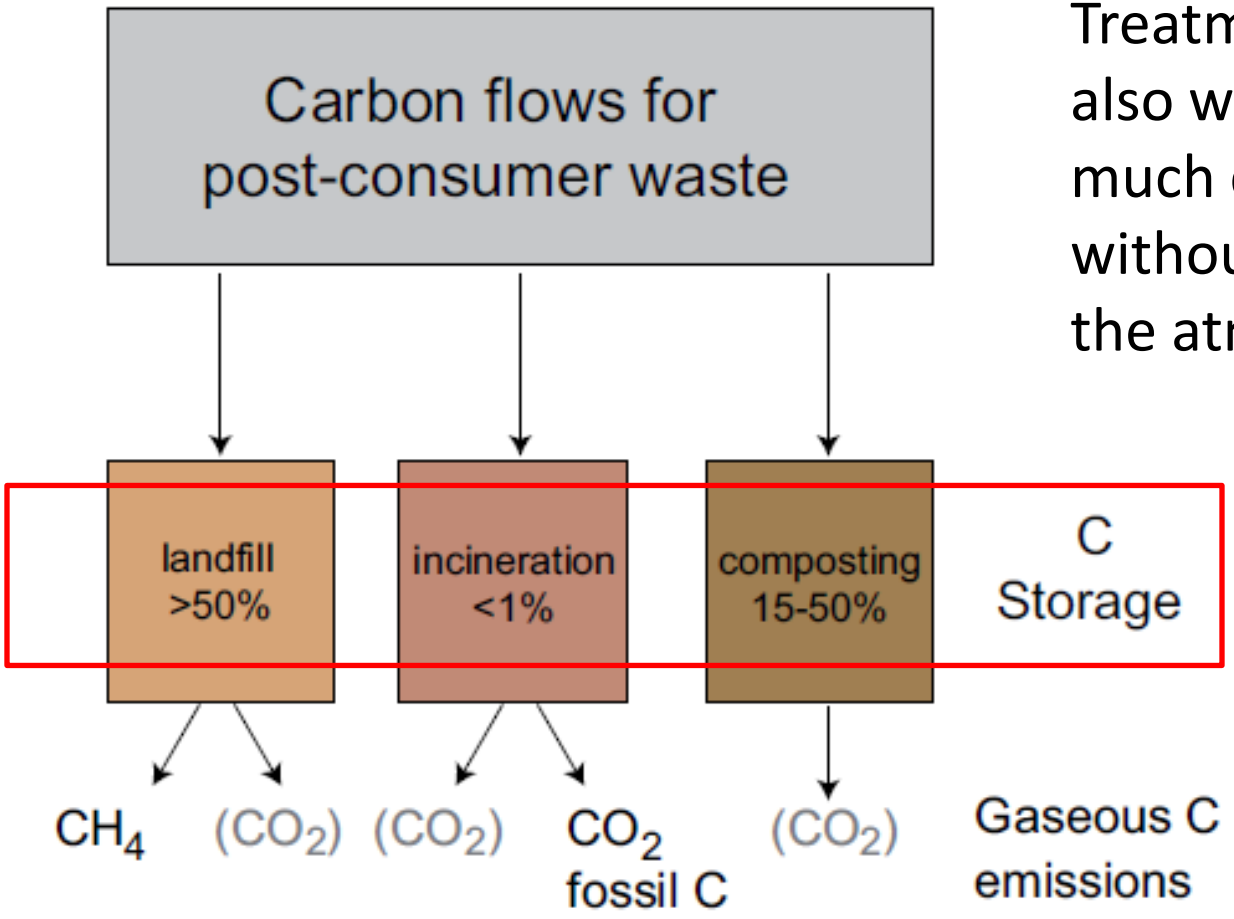
Thank you for your attention

GHG emissions from different treatment technologies



Methane is responsible for the largest climate impact

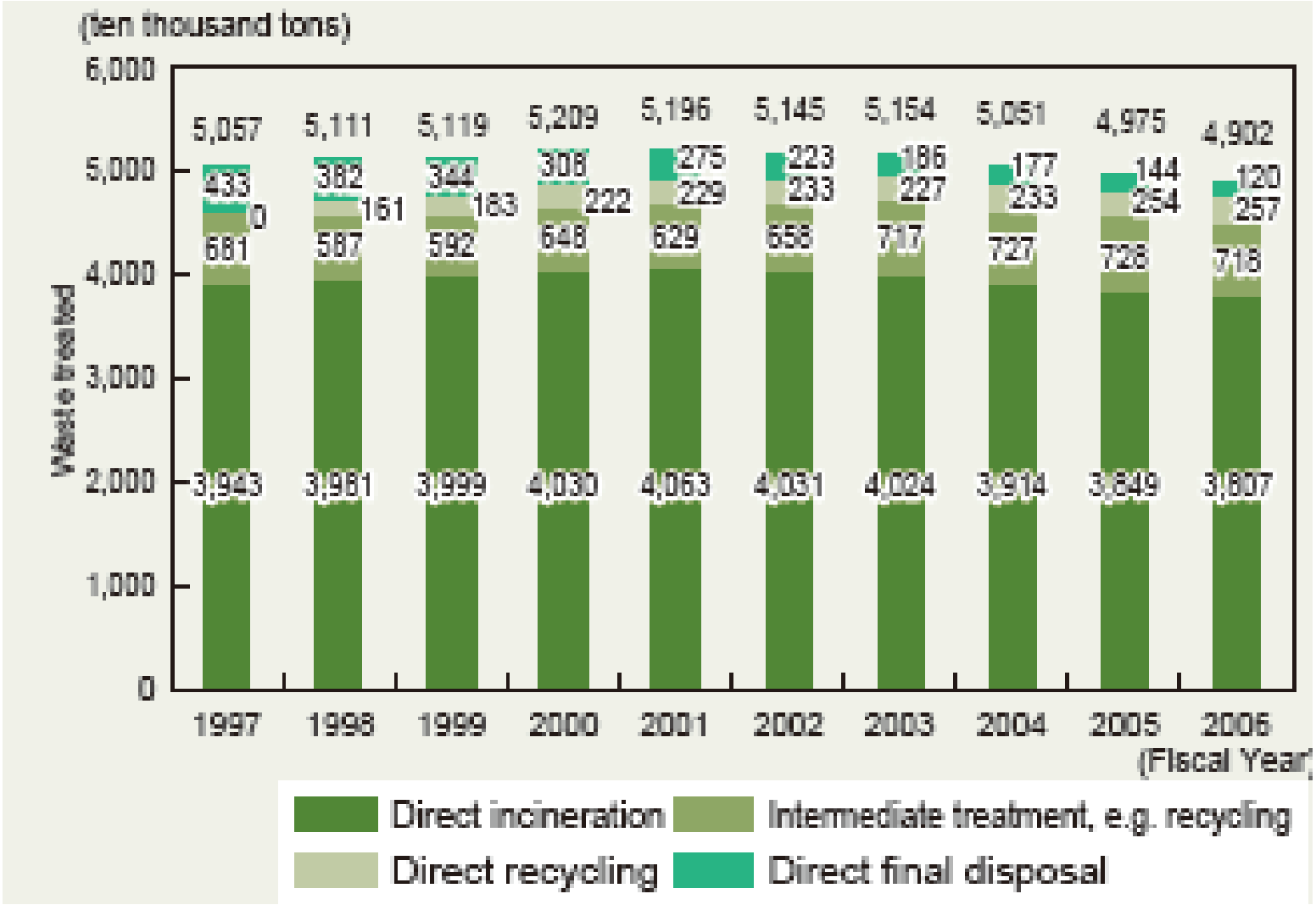
Carbon storage



Treatment options differ also with respect to how much carbon is stored without being released to the atmosphere

A. Developed countries

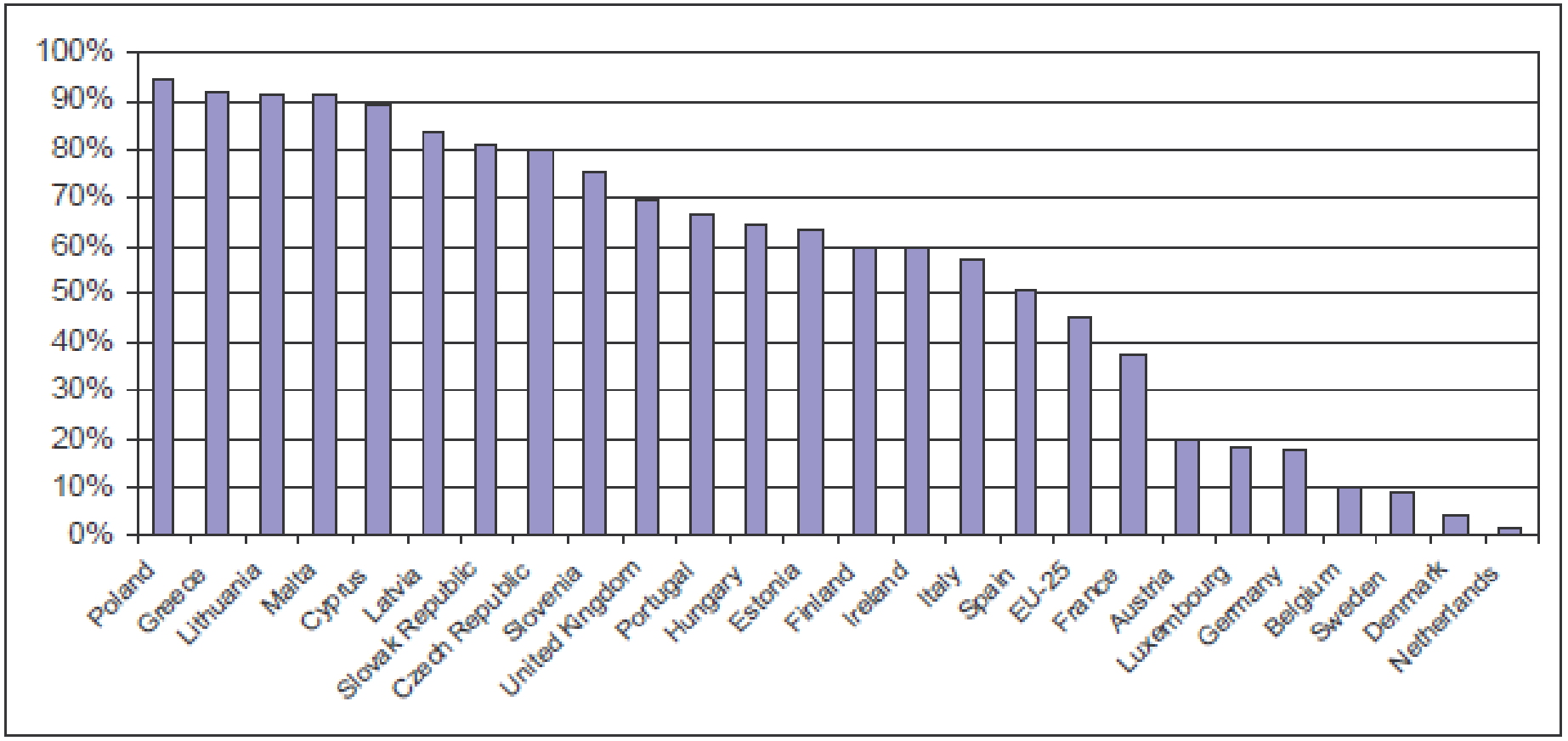
Generation and treatment of municipal waste in Japan



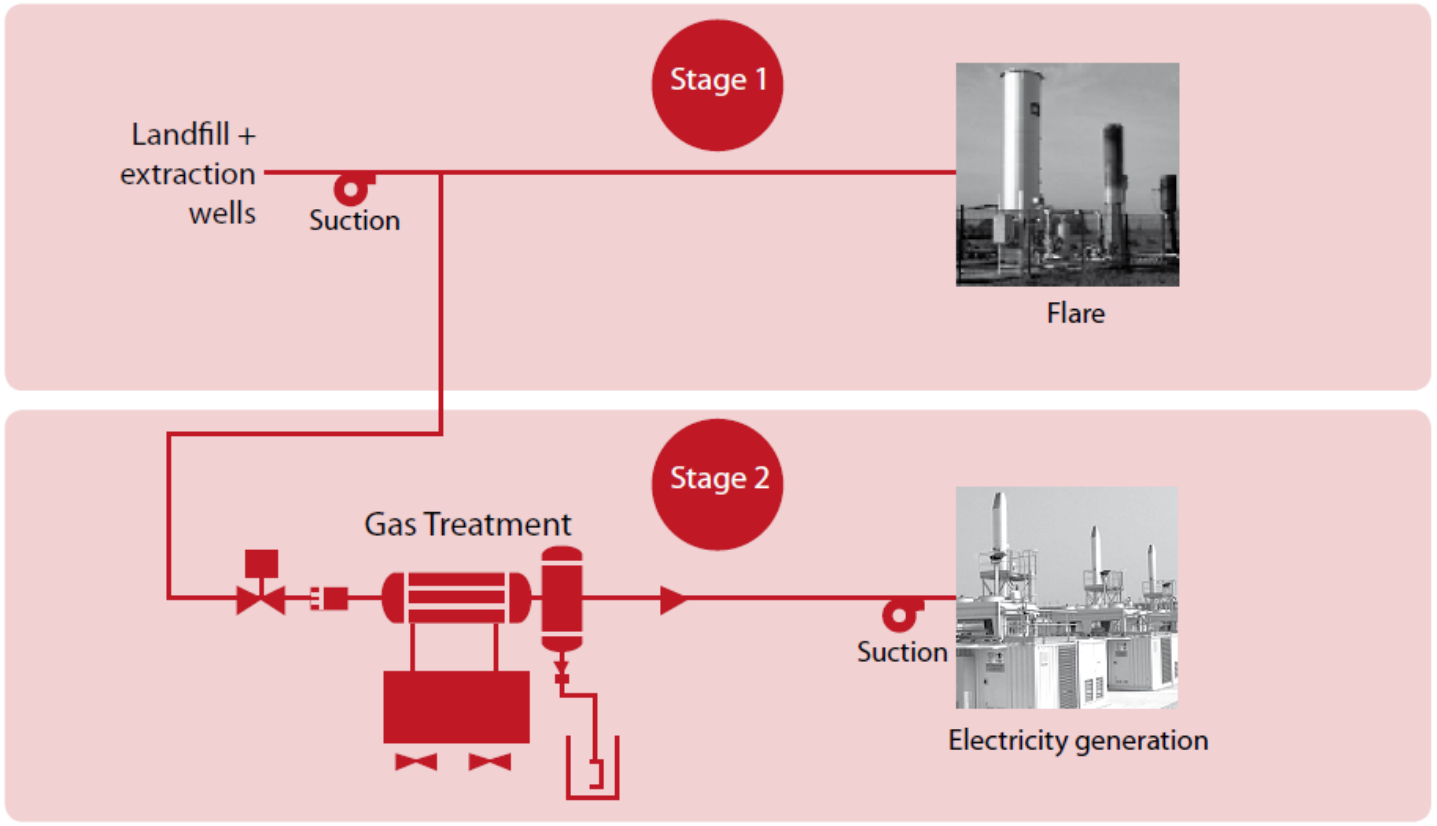
Waste incinerator in Japan

- 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

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

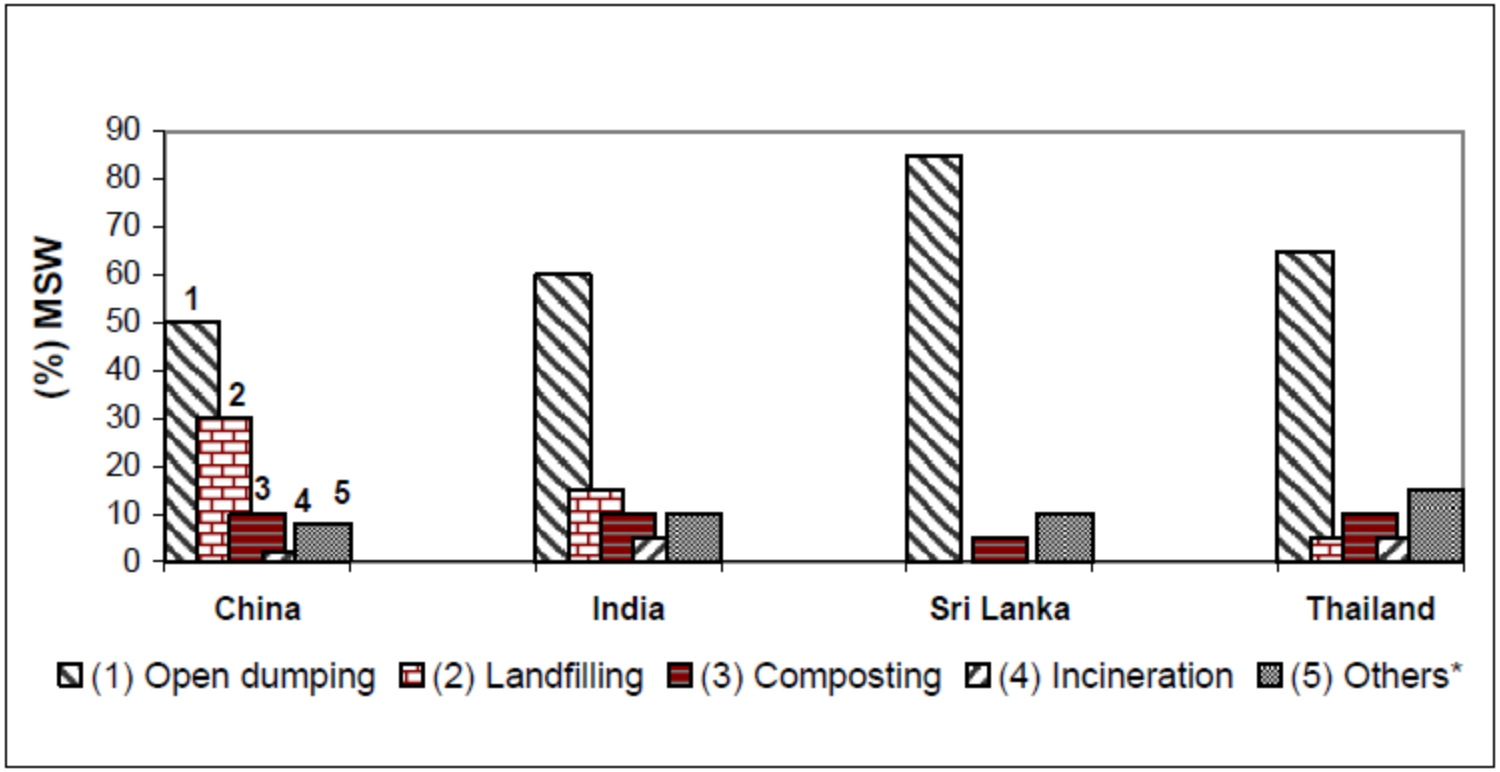
B. Developing countries

Waste generation and composition in developing Asian countries

Country	Solid waste generation (million ton/yr)	Waste generation per urban capita (kg/day)	Waste composition (%)					
			Food	Paper	Plastic	Metal	Glass	Others
China[a]	120	1.15	45-55	10-20	5-15	2-4	2-4	2-36
India[c]	42[b]	0.4 (0.2-0.6)[b]	40	5	4	1	2	47
Indonesia[e]	22.5[d]	0.76[e] (0.6-0.85)[d]	74	10	8	2	2	2
Thailand[f]	14.7	1.1[g]	64	8	17	2	3	3-6
Viet Nam[h]	12.8	0.4 (0.3-0.7)	55-65	4-25[i]	16	6	7	20
Philippines[j]	11[k]	0.5	45	16	15	6[l]	<9	15
Malaysia[m]	8.7	0.9[n]	49	17	10	2	4	18
Bangladesh[o]	4.87[p]	0.41	68	10	5	0.3	1.1	15.6
Cambodia[p]	no data	0.34	66	3	14	1	1	15
Laos[q]	no data	0.75	60	10-15			10-15	10

Sources: [a]Rissanen and Naarajärvi, 2004; [b]Kurian, 2007; [c]Toxic Link, 2002; [d]Balifokus et al., 2006; [e]Zurbrugg, 2002; [f]PCD, 2009; [g]IBRD, 1999; [h]World Bank, 2004a; [i]Hanoi University of Science, 2004; [j]World Bank, 2004b; [k]Aguinaldo, 2008; World Bank, 2001; [l]JICA, 2006; [m]Lee and Hanipiah, 2009; [n]DOE et al., 2004; [o]Waste Concern, 2005; [p]Maclaren, 2005; [q]Keodalavong, 2007.

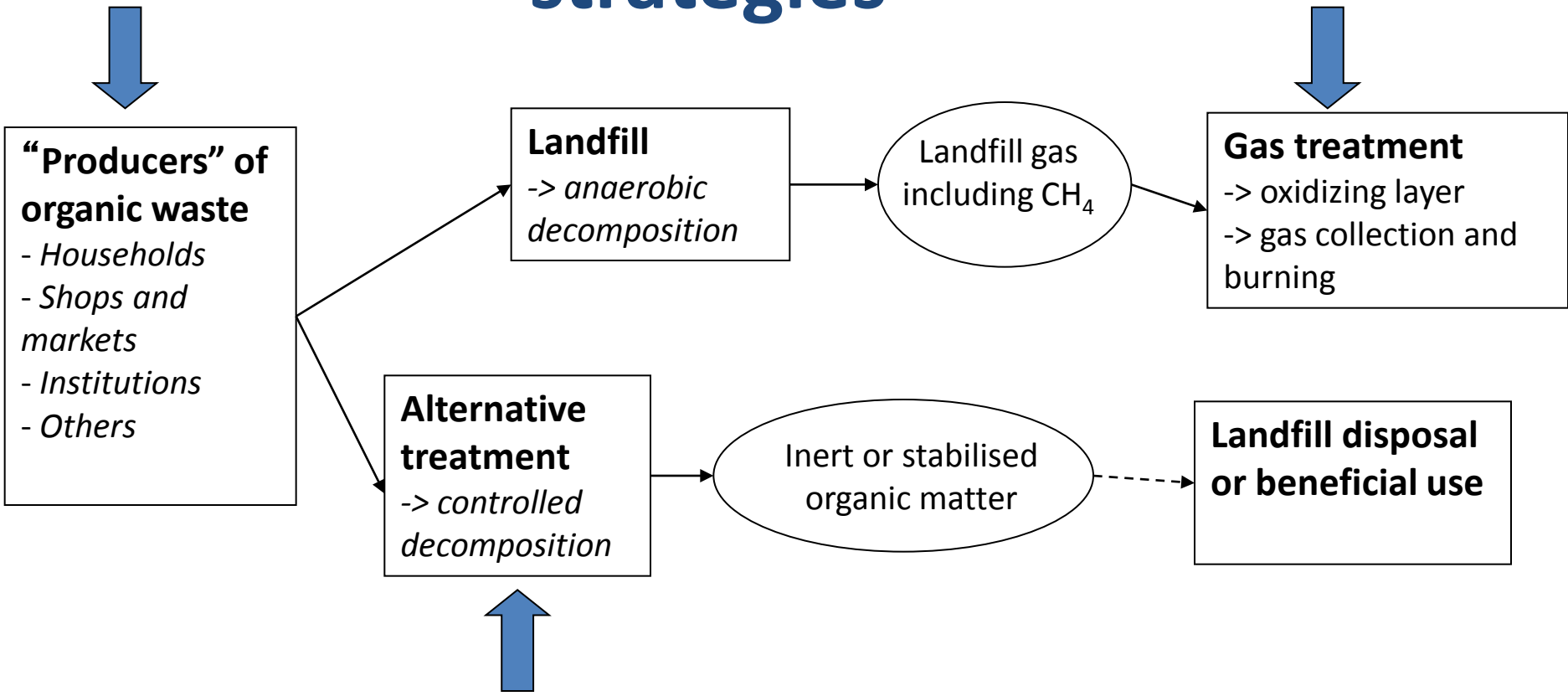
Waste treatment in developing Asia



3 Basic strategies

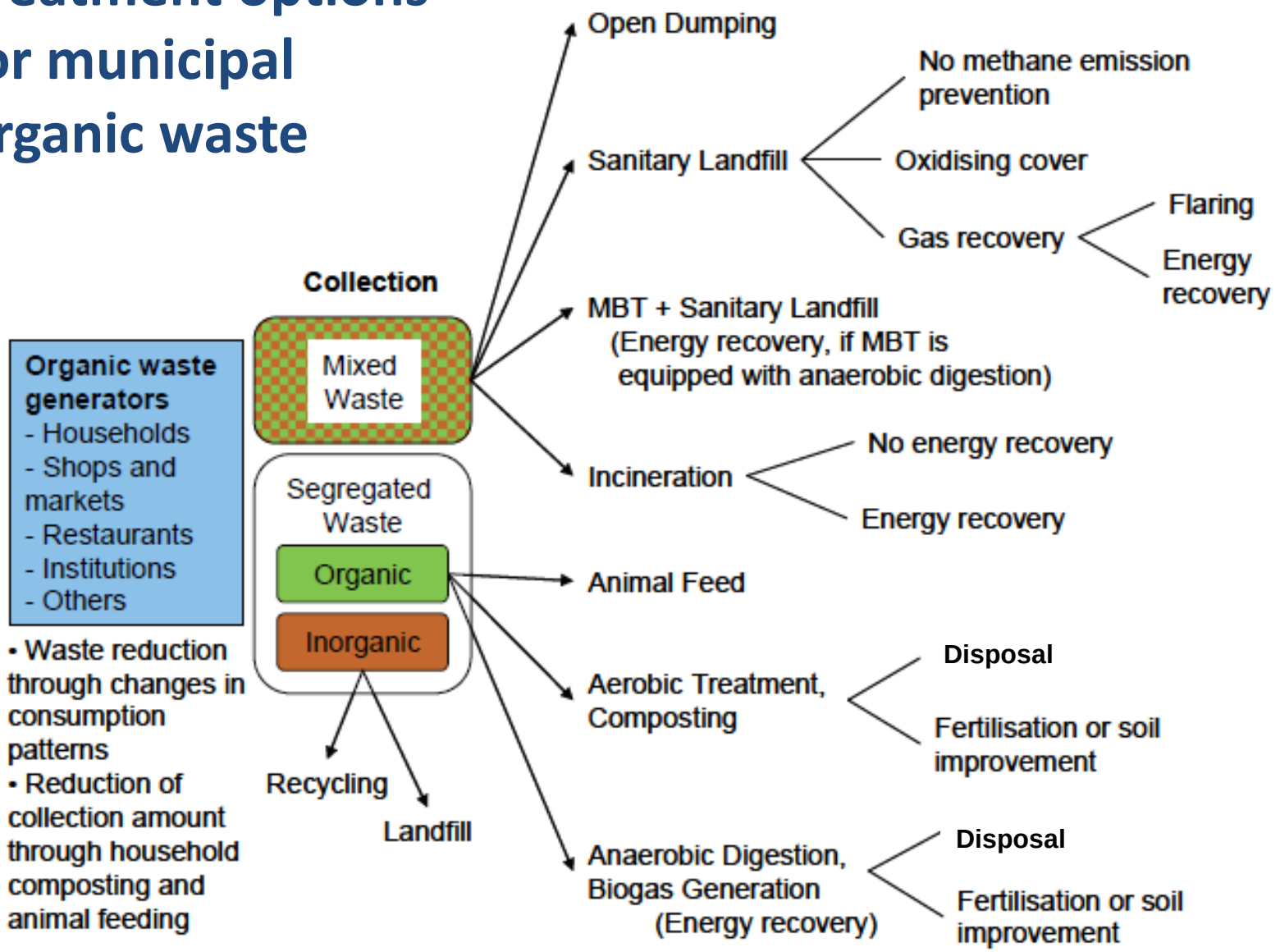
Strategy 1:
Reduce waste generation

Strategy 3:
Oxidise CH_4 generated in landfill



Strategy 2:
Decompose organic matter aerobically so that CH_4 emissions are avoided, or anaerobically in a closed tank and collect the CH_4

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

GWP values from 2007 IPCC AR4	GWP time horizon		
	20 years	100 years	500 years
Carbon dioxide	1	1	1
Methane	72	25	7.6
Nitrous oxide	289	298	153

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.

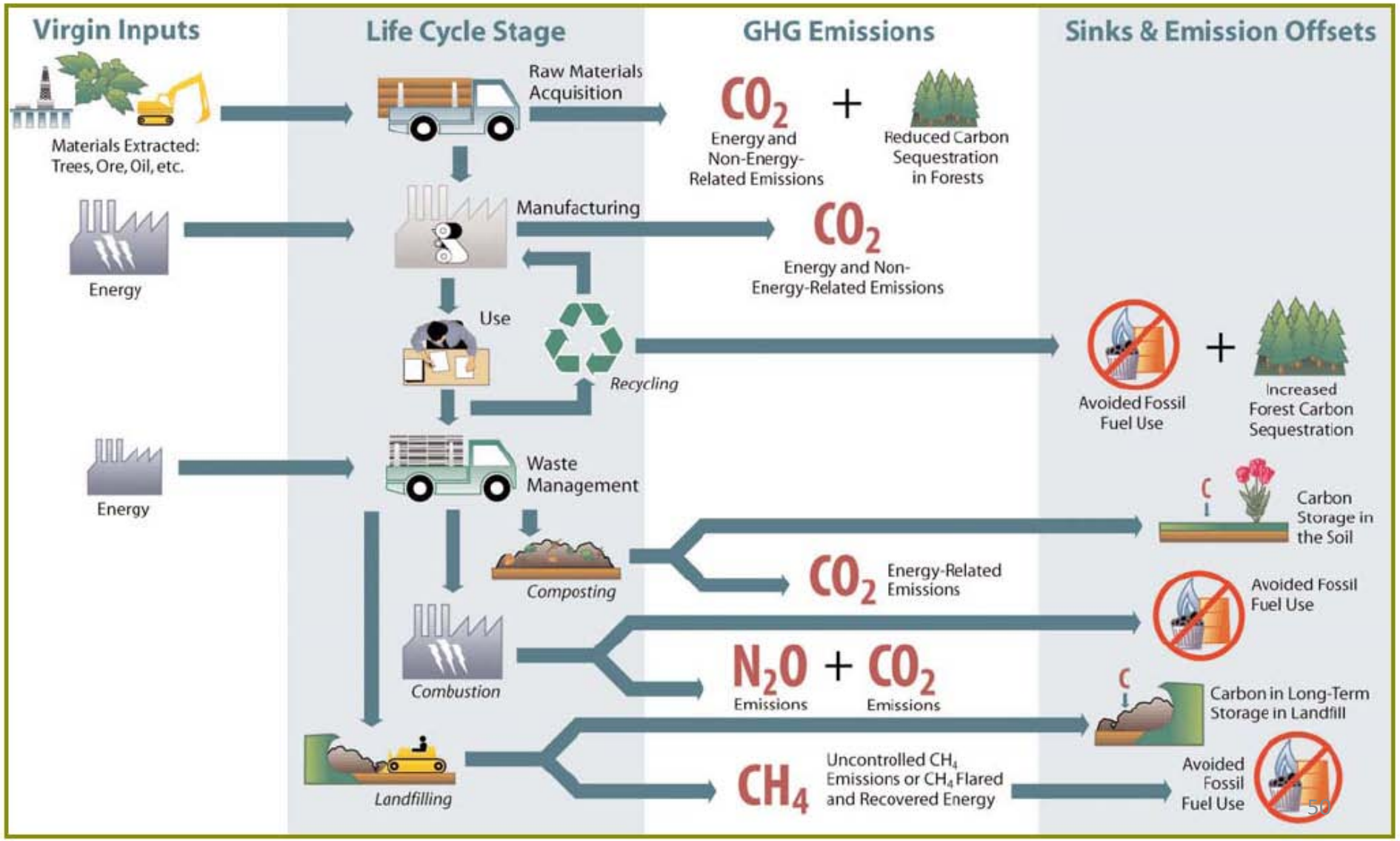
Shindell, D.T., Faluvegi, G., Koch, D.M. et al. (2009). Improved Attribution of Climate Forcing to Emissions. *Science*. 326:716-718.

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

Country	National climate change policy	Indication of the waste sector	3Rs approach to climate change included
China	2007	Yes	Reduce, Recovery, Utilization
India	2007	Yes	Recycling
Indonesia	2007	Yes	5Rs for industry & 3Rs for domestic waste
Thailand	2008	Yes	3Rs
Bangladesh	2008	Yes	No
Cambodia	2000	Yes	No
Philippines	1999	One word	No
Malaysia	2000	No	No
Lao	2002	No	No
Viet Nam	2003	No	No

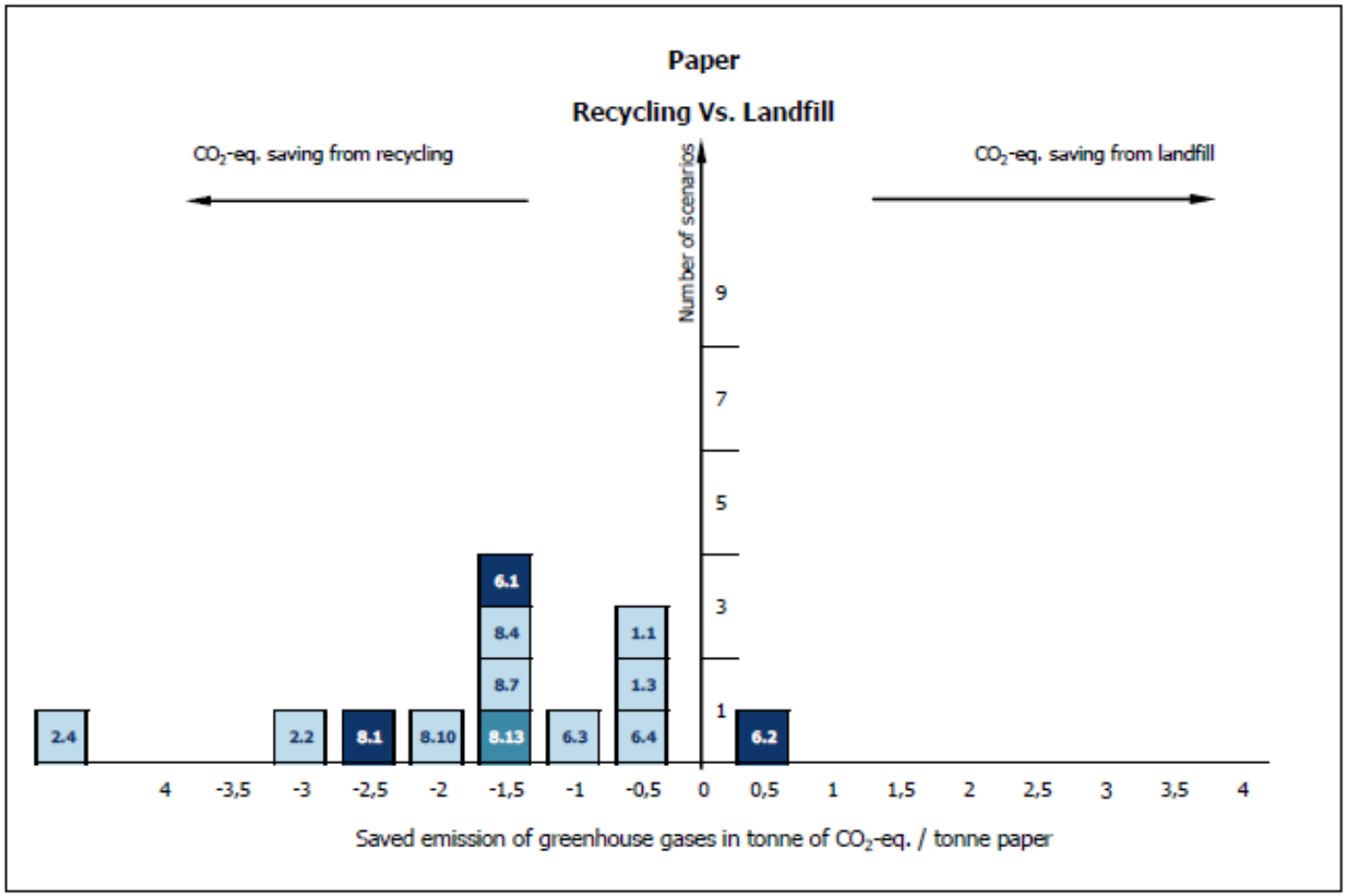
Recycling of other waste fractions

Product reuse and materials recycling have upstream climate benefits



Climate benefits of paper recycling

Comparison of 13 LCA studies



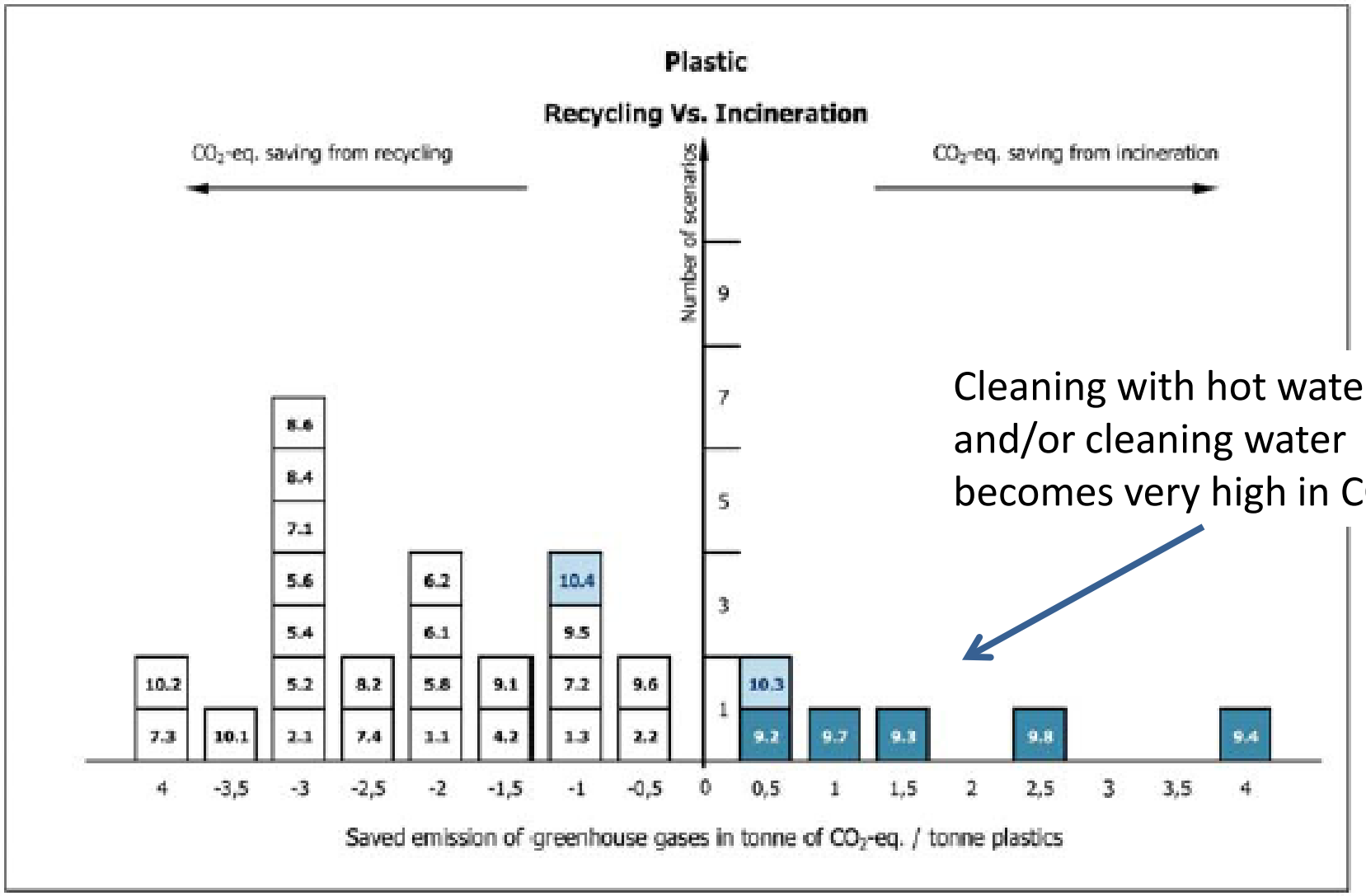
X.Y Newsprint, newspapers, magazines

X.Y Mixed paper, graphic paper, office paper

X.Y 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