Sandec
Sanitation, Water and
Solid Waste for Development

Eawag:
Swiss Federal Institute of Aquatic
Science and Technology

eawag
aquatic research

Solid Waste Management in low- and middle-income countries

Dorian Tosi Robinson, Eawag/Sandec

EPFL 2024

About me

Dorian Tosi Robinson

- Environmental Engineer, graduated 2017 at EPFL
- Expertise in Solid Waste Management and Drinking Water for Development
- Int. experience: Nepal, Guatemala, Vietnam, Costa Rica, Nicaragua, Panama, Honduras, Dominican Republic, El Salvador.
- Project officer at Sandec

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Outline of the lecture

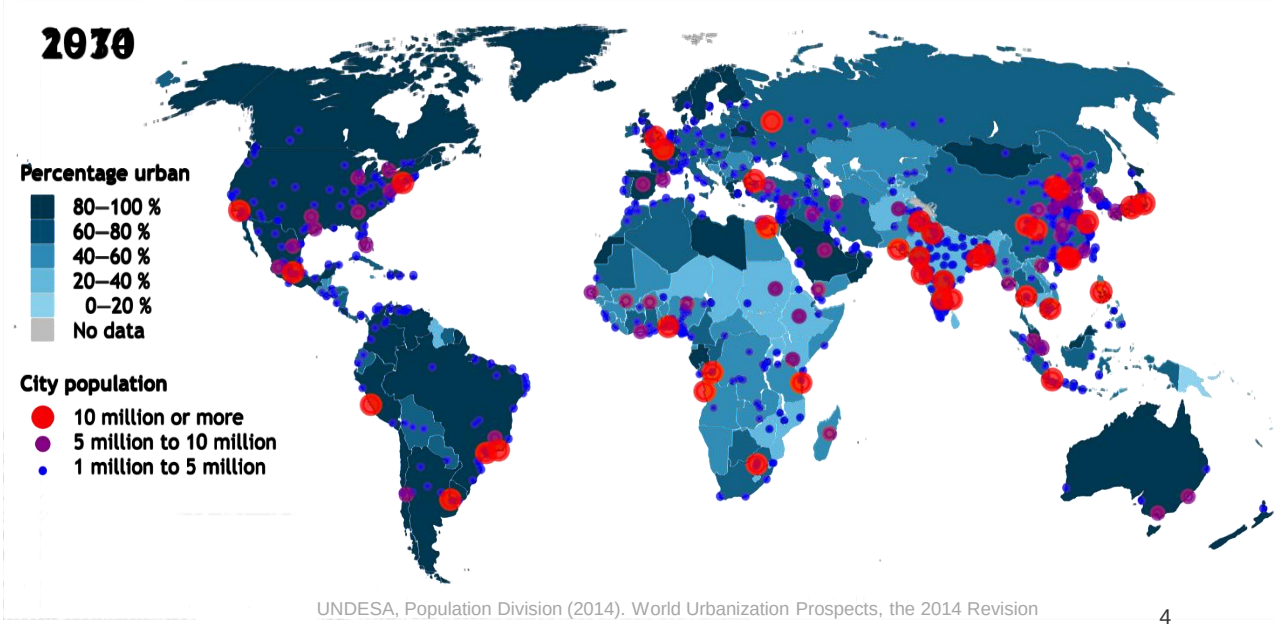
- Challenges and Situation
- Definitions and ISWM Framework
  - Physical elements
  - Governance aspects
- Recycling & Organic waste treatment technologies
  - Composting
  - Anaerobic Digestion
  - Black Soldier Fly
- Take home messages

Current challenges in LAMI Countries

Main challenges and impacts

Socio-economic conditions

- Rapid population (and industrial) growth
- Migration to urban areas (urbanization)



UNDESA, Population Division (2014). World Urbanization Prospects, the 2014 Revision

Current challenges in LAMI Countries

Main challenges and impacts

Socio-economic conditions

- Rapid population & economic growth
- Migration to urban areas (urbanization)
- Lack of sufficient funds and affordable services (SWM not a priority)
- Experience in adequate waste management lacking

Neighborhood dump, Mumbay, India

Solid waste management systems are often poorly run

- **Collection:** Inadequate coverage of collection service
- **Recycling:** Unregulated (formal and informal sector)
- **Disposal:** Improper disposal in open dumps or burning

Informal sector in Cochabamba, Bolivia

Your turn:

What are impacts of improper waste management?

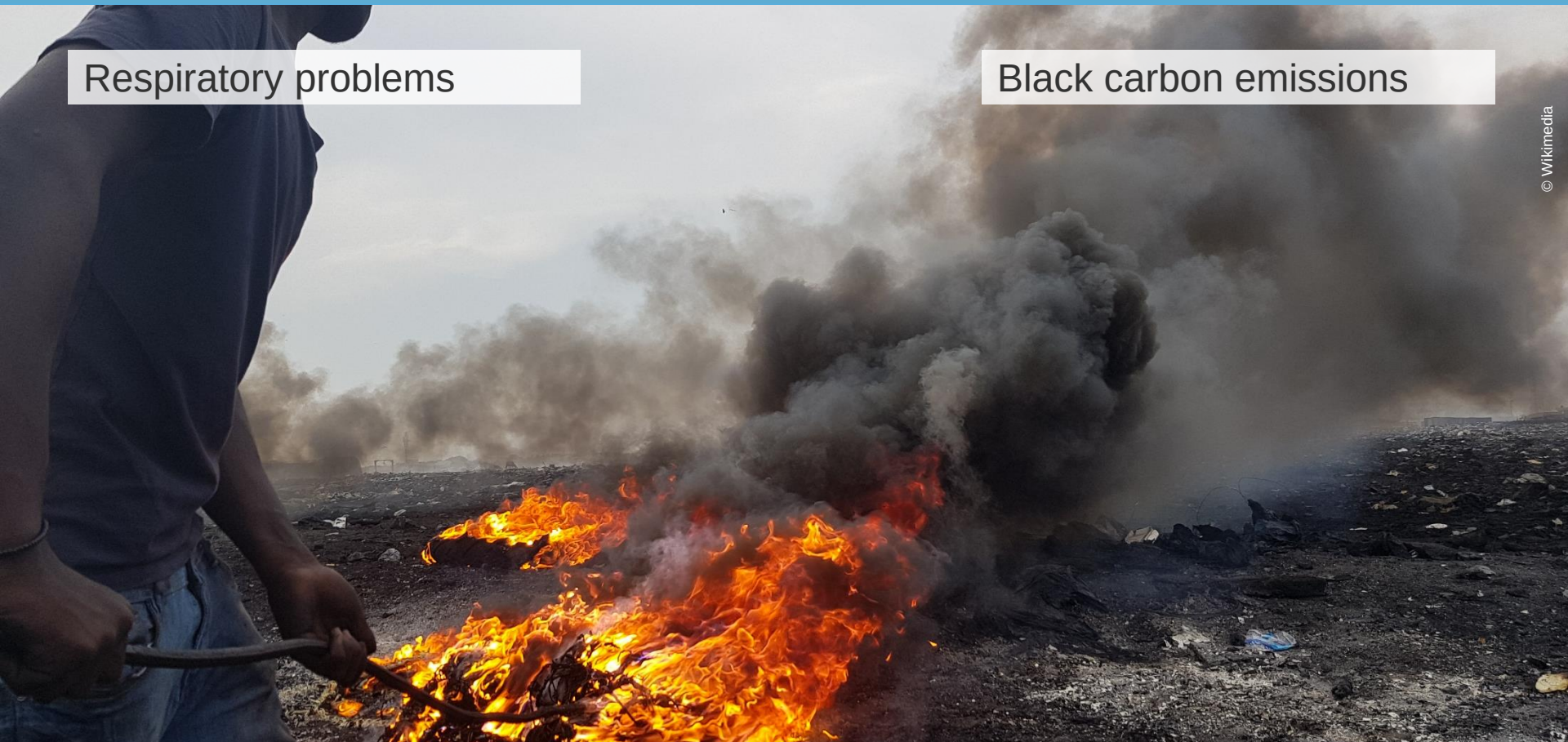
Environmental Threats

Environmental / Health Threats

(Ground)water pollution

Environmental / Health Threats

Environmental / Health Threats



Respiratory problems

Black carbon emissions

© Wikimedia

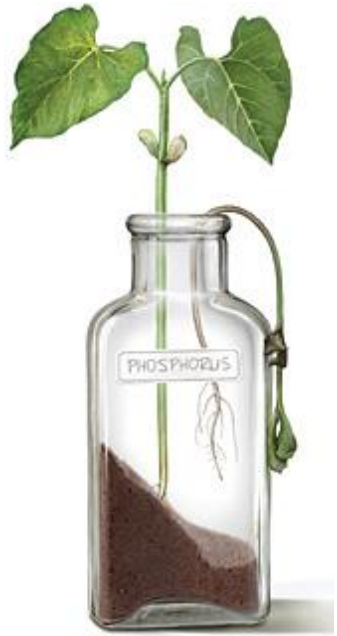
Health Threats

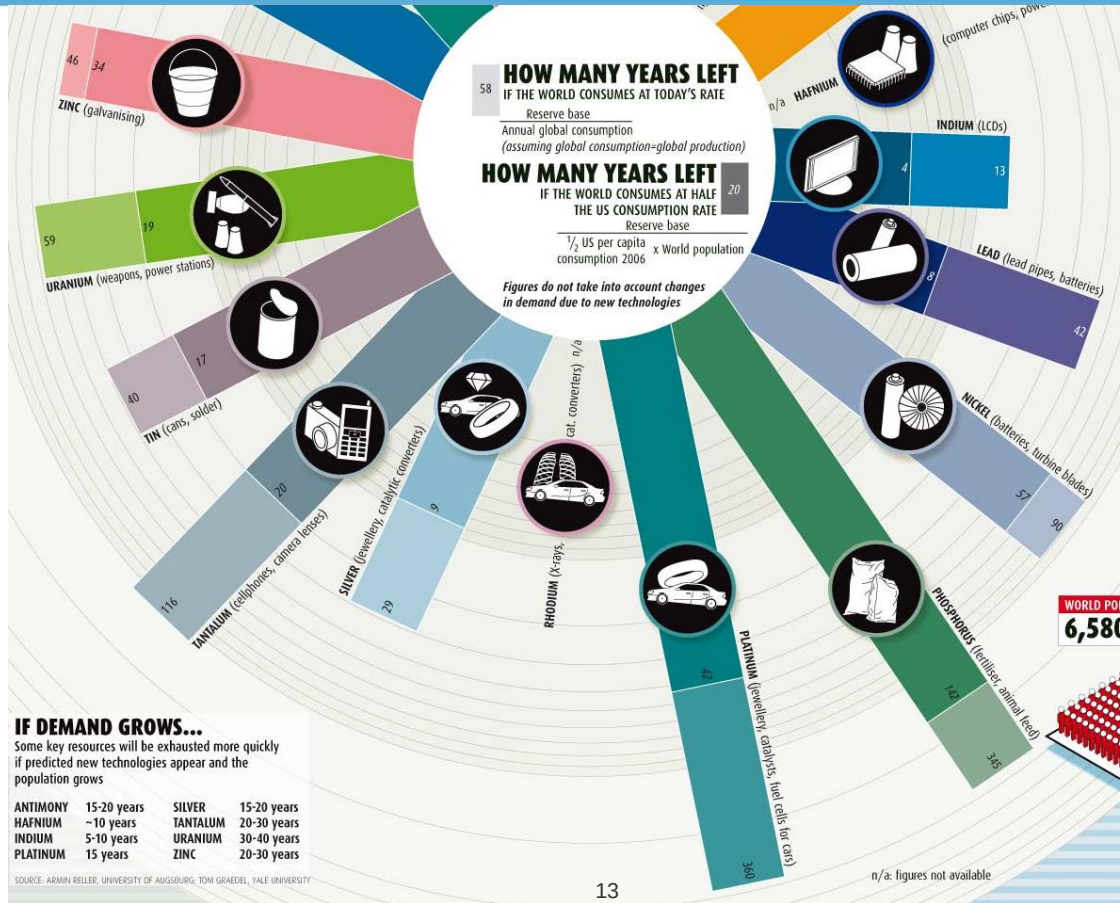
Attract pests and rodents

Resource depletion

Loss of nutrients

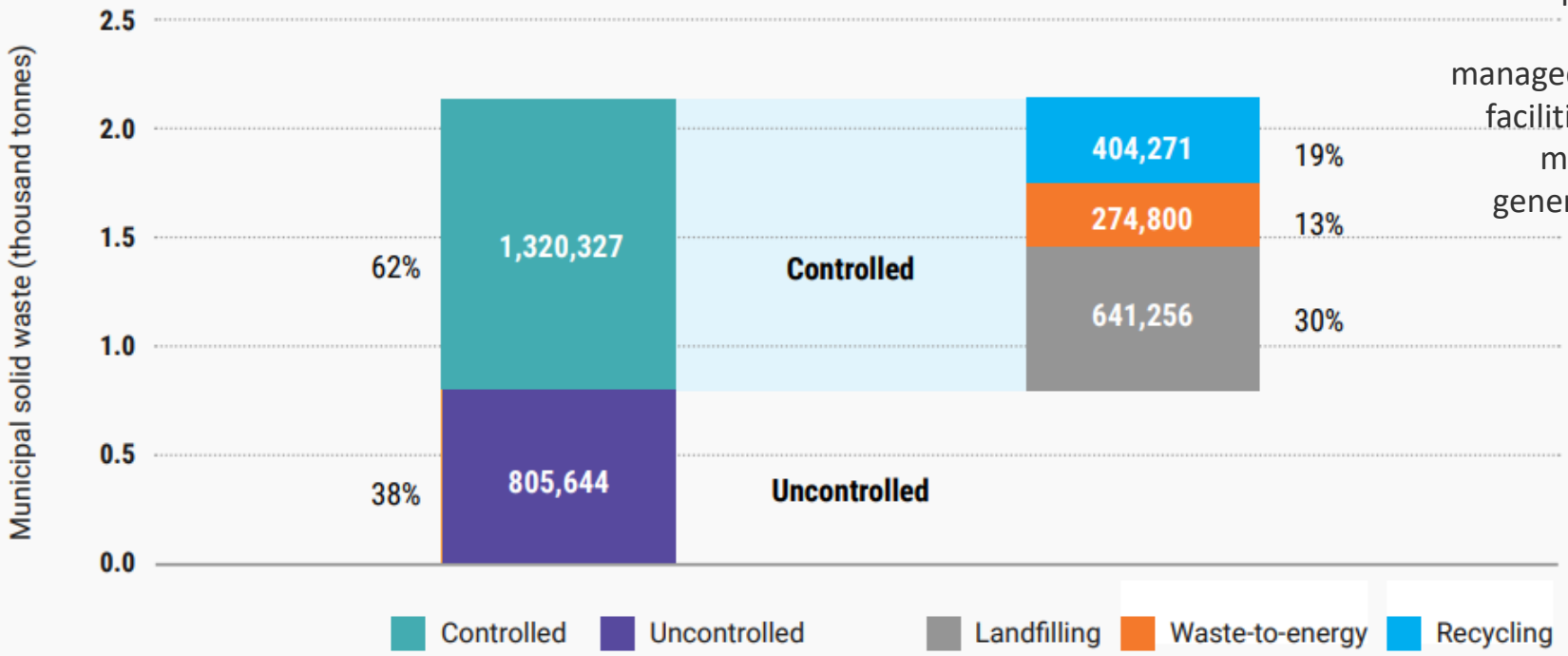
Resource depletion





38% of the waste is not under control

Figure 7: **Global municipal solid waste destinations in 2020: Controlled (landfilling, waste-to-energy recycling) and uncontrolled.**



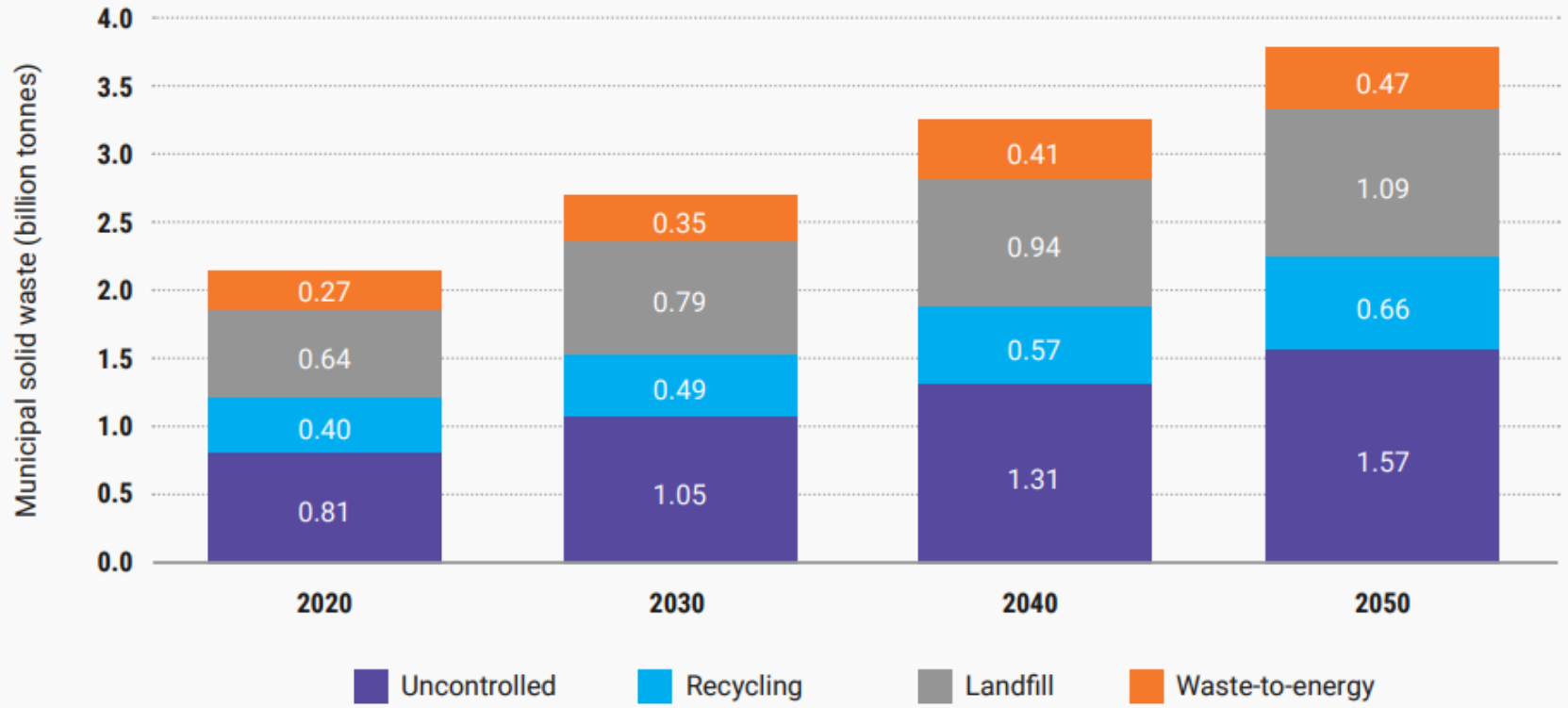
UNEP (2024). Global Waste Management Outlook 2024. Beyond an age of waste Turning rubbish into a resource.

SDG Indicator

11.6.1: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities

Uncontrolled waste expected to almost double

Figure 9: Projected global municipal solid waste destinations in 2030, 2040 and 2050 compared with 2020.

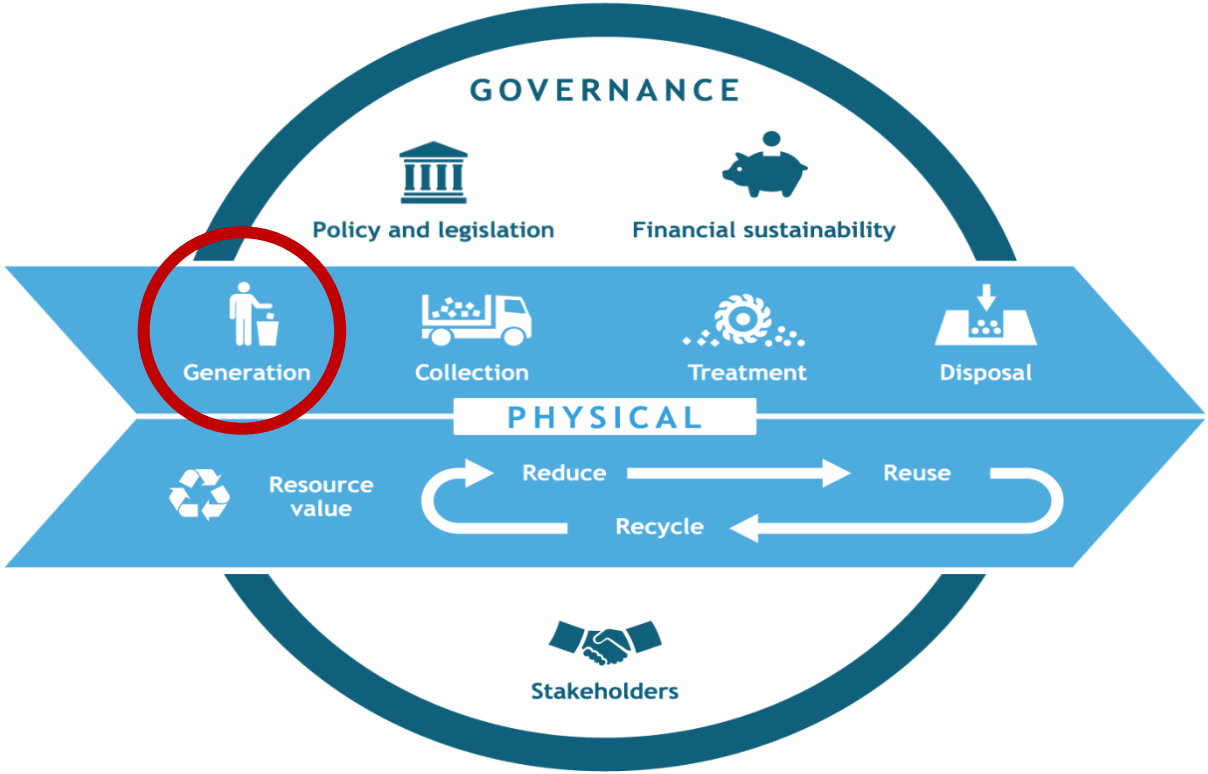


UNEP (2024). Global Waste Management Outlook 2024. Beyond an age of waste Turning rubbish into a resource.

How do we start bringing change?

We need a structure to understand the system!

Integrated Sustainable Waste Management (ISWM) Framework



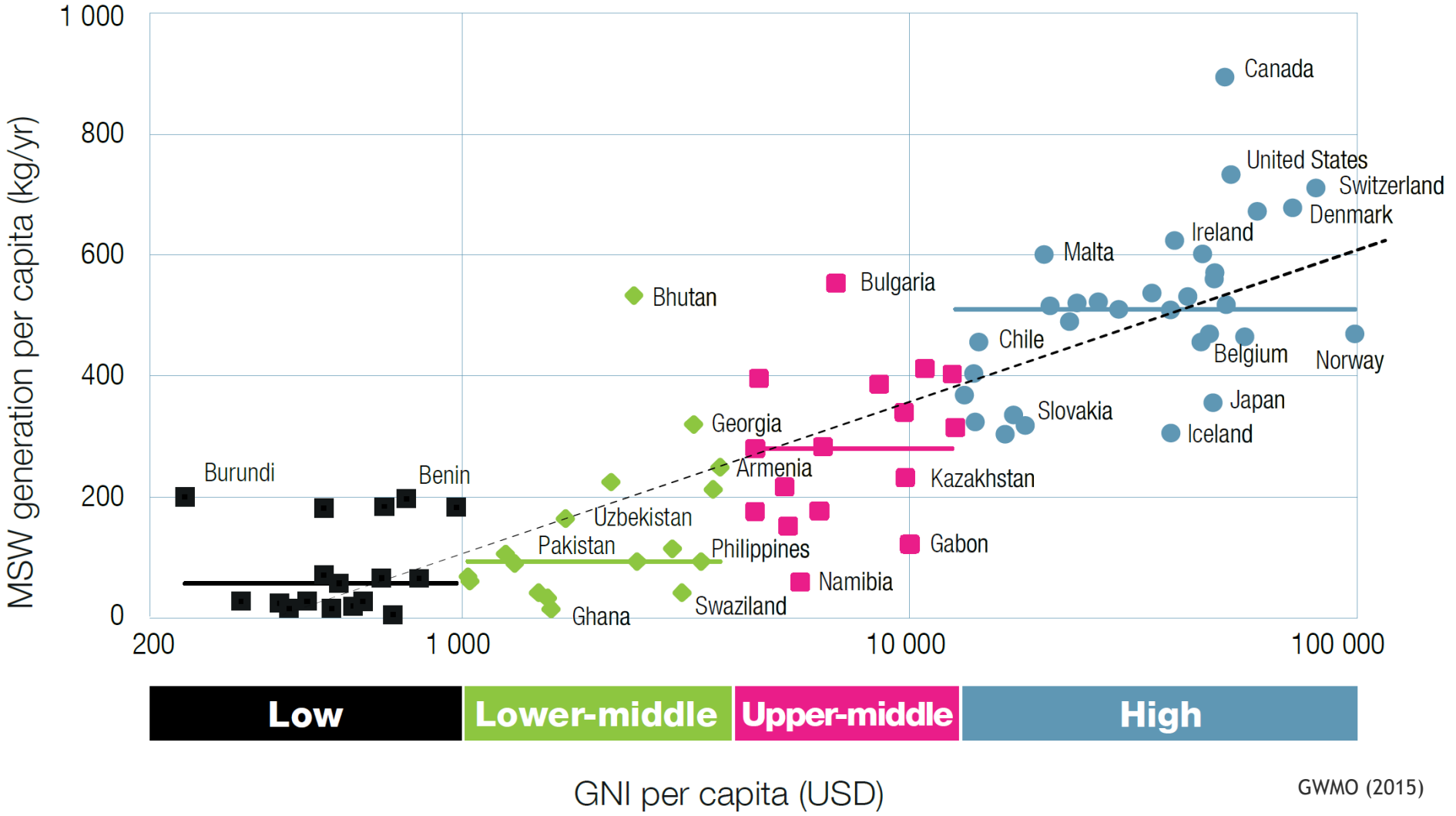
Source: MSWM-MOOC Sandec (2016)

Generation

Two important aspects:

a) MSW generation:

	Lahore (Pakistan)	Guadalajara (Mexico)	Belfast (Northern Ireland)
ton/year	1,916,000	2,000,000	149,000


1 000
800
600
400
200
0
MSW generation per capita (kg/yr)
Canada
United States
Switzerland
Denmark
Ireland
Malta
Bulgaria
Bhutan
Chile
Belgium
Norway
Japan
Slovakia
Iceland
Georgia
Armenia
Kazakhstan
Burundi
Benin
Uzbekistan
Pakistan
Philippines
Gabon
Namibia
Swaziland
Ghana
200
1 000
10 000
100 000
Low
Lower-middle
Upper-middle
High
GNI per capita (USD)
GWMO (2015)

Generation

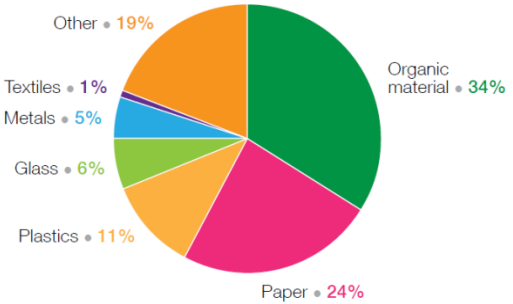
Two important aspects:

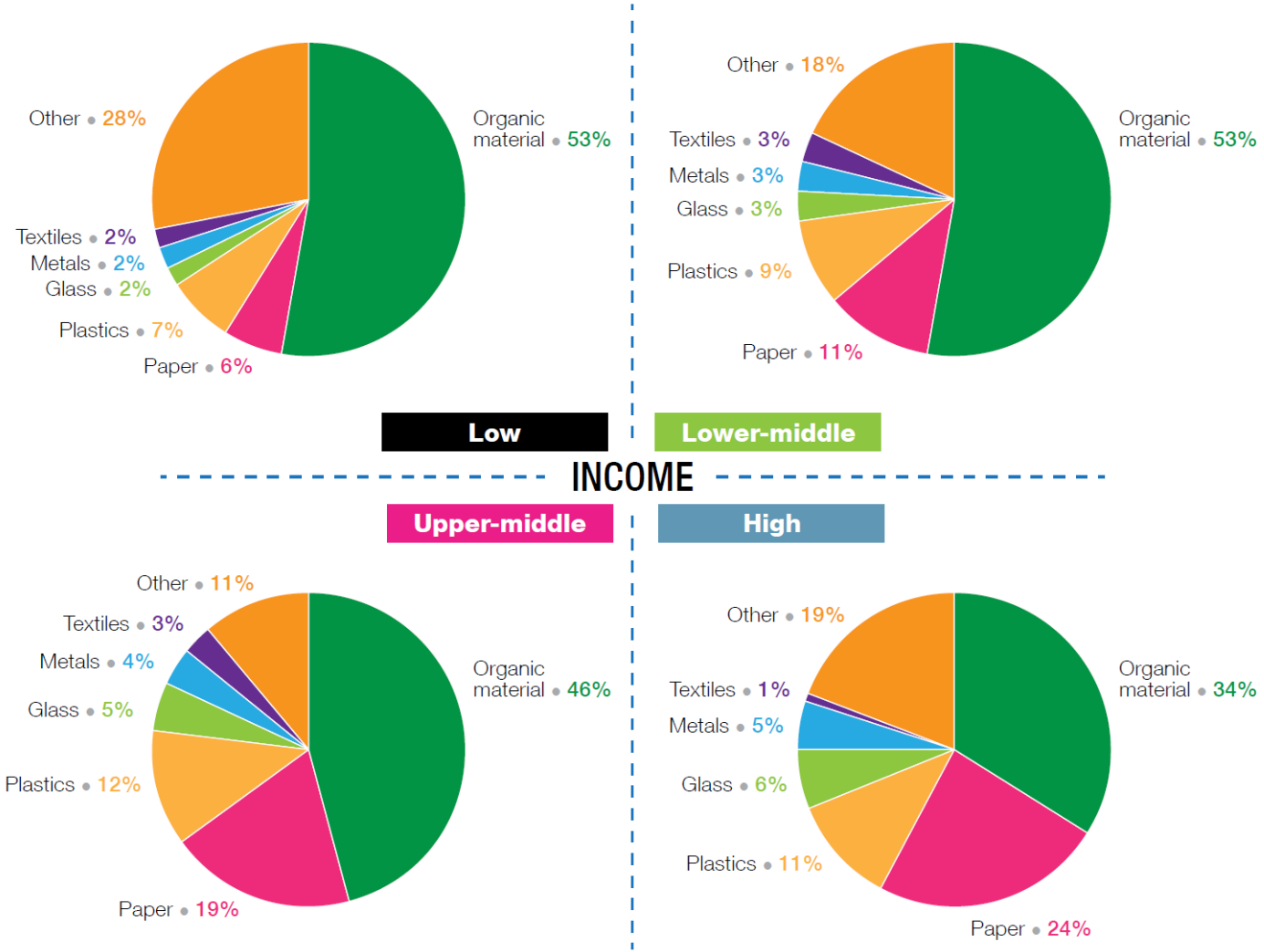
a) MSW generation:

	Lahore (Pakistan)	Guadalajara (Mexico)	Belfast (Northern Ireland)
ton/year	1,916,000	2,000,000	149,000
Kg/year per capita	219	440	683
Kg/day per capita	0.6	1.2	1.9

b) Characterization: MSW composition (% of mass)

a) $$Fraction\ X = \frac{Mass\ of\ Fraction\ X\ (kg\ or\ ton)}{Total\ Mass\ of\ generated\ MSW (kg\ o\ ton)}$$




Low
Other • 28%
Organic material • 53%
Textiles • 2%
Metals • 2%
Glass • 2%
Plastics • 7%
Paper • 6%
Lower-middle
Other • 18%
Organic material • 53%
Textiles • 3%
Metals • 3%
Glass • 3%
Plastics • 9%
Paper • 11%
INCOME
Upper-middle
Other • 11%
Textiles • 3%
Metals • 4%
Glass • 5%
Plastics • 12%
Organic material • 46%
Paper • 19%
High
Other • 19%
Organic material • 34%
Textiles • 1%
Metals • 5%
Glass • 6%
Plastics • 11%
Paper • 24%

GWMO (2015)

Generation

Characteristics of solid waste

		Low-Income Countries*	Middle-Income Countries**	High-Income Countries
Waste generated	kg/cap/day	0.4–0.6	0.5–0.9	0.7–1.8
Waste density	kg/m^3	250–500	170–330	100–170
Water content	%	40–80	40–60	20–30
Composition				
Organic		40–85%	20–65%	20–50%

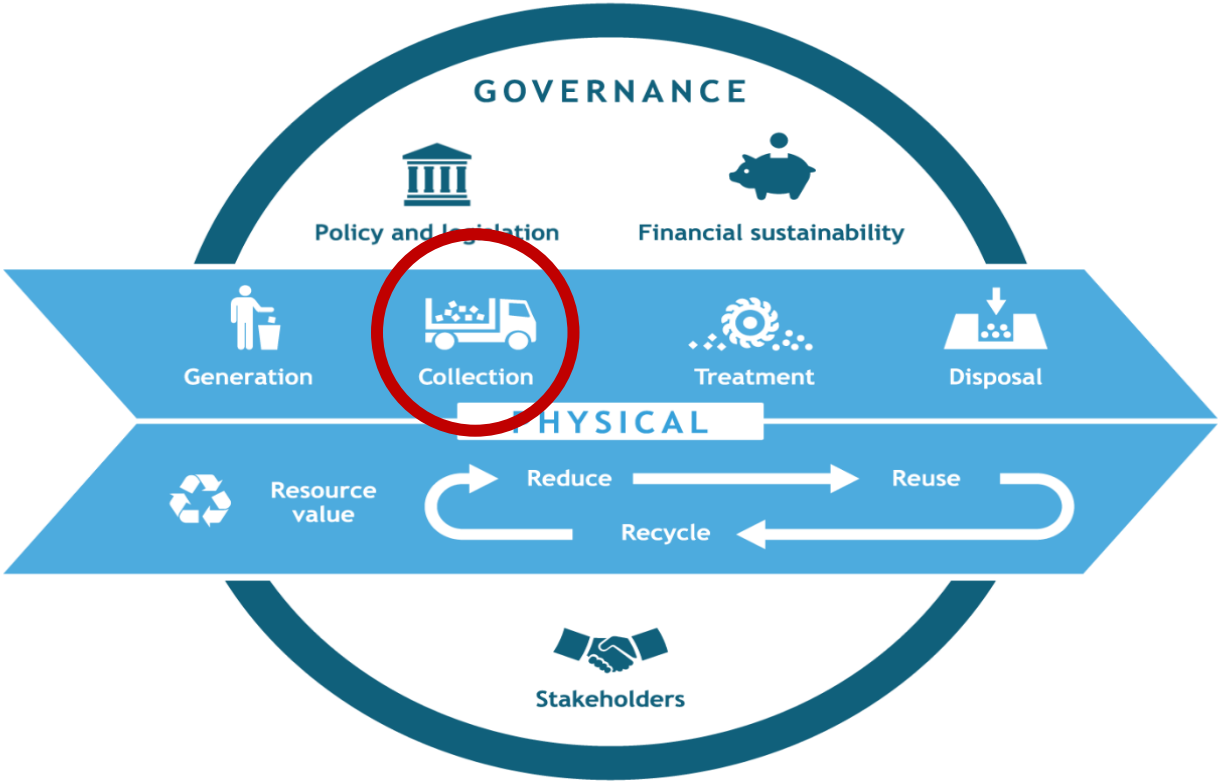
Low-income: GDP < US$ 360 per year per capita
Middle-income: GDP > US$ 360 per year per capita.
High-income: < US$ 3'500 per year per capita.

(Cointreau, 1982, in Zurbrügg, 2003)

Important for:
- Policy and measures
- Waste collection system
- Treatment and disposal options

Data collection: waste audit

ISWM Framework



Source: MSWM-MOOC Sandec (2016)

Collection and transport

How does that work?

Generation

Primary collection

Transfer station

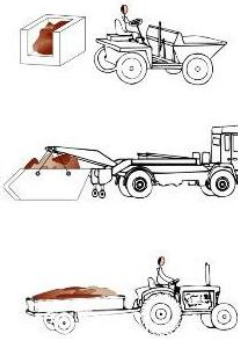
Secondary collection

Collection and transport

How does that work?

Generation

Secondary collection



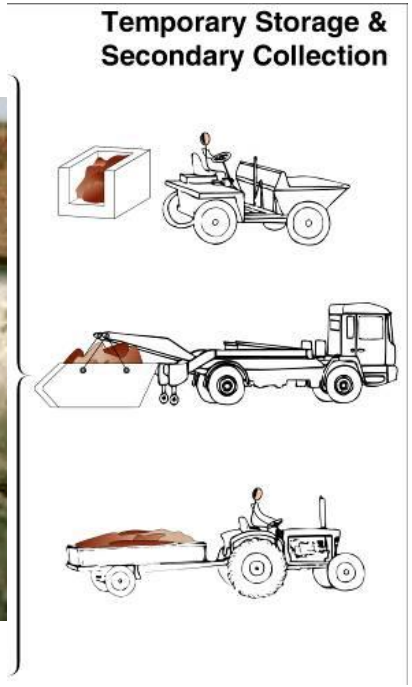
Collection and transport

Primary collection

- **Primary waste collection vehicles**
  - Local construction with local materials
  - Easy maintenance and repair
  - Low price
  - Adapted to local situation
  - **! Volume and weight have to match the carrier !**
  - **! Needs clear management structure, roles and tasks !**

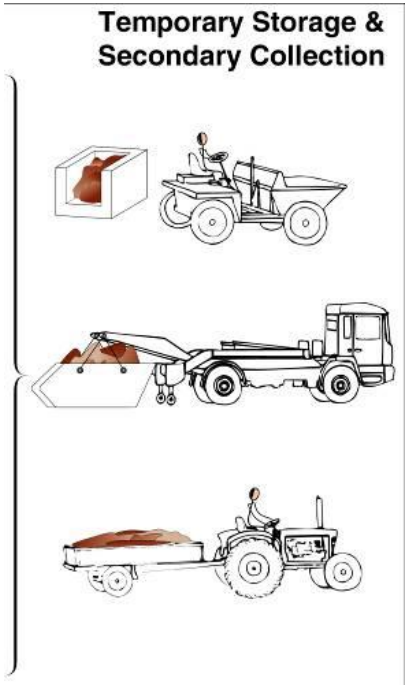
Collection and transport

Transfer points



Collection and transport

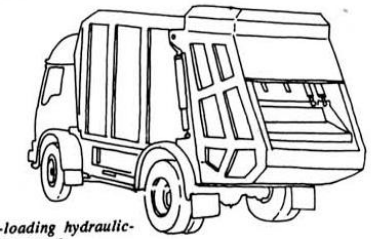
Transfer points



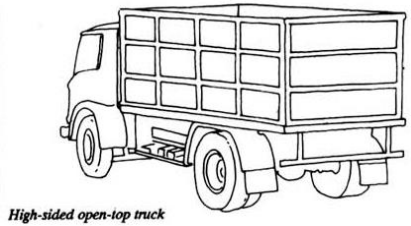
«Technology» includes operation and management !!

Collection and transport

Compactor truck : Yes or No?



Rear-loading hydraulic-compactor truck



High-sided open-top truck

- Compactor trucks work well when:
  - Wider paved streets
  - Easy and quick pick up (in bags or containers)
  - **Low density** and low moisture content

- Non-compactor trucks work well where:
  - Wet or dense waste
  - Inexpensive labor
  - Limited access to highly skilled maintenance or specialized spare parts
  - Downtime for maintenance shall be kept minimal

Collection and transport

Compactor truck : Yes or No?

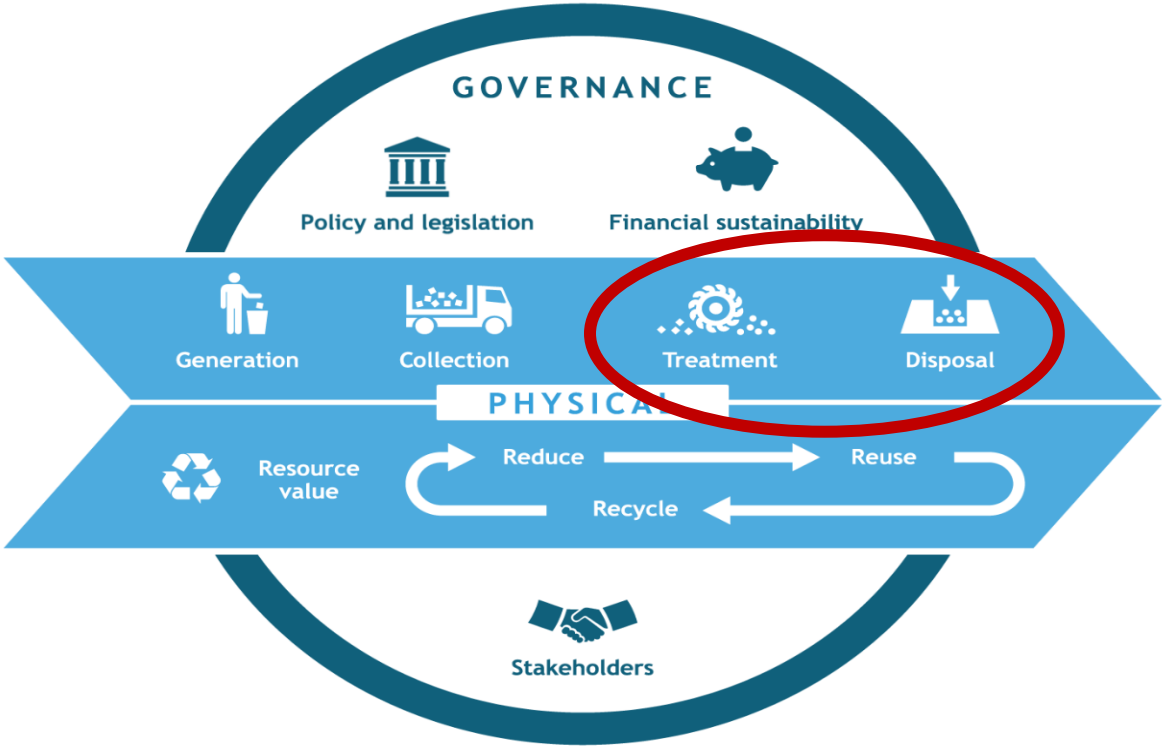
Rear-loading hydraulic-compactor truck

High-sided open-top truck

Facts:

- Collection uses a large part of the municipal budget
- Equipment influences cost efficiency
- Services provided to the richer…the urban poor suffer most from the lack of service
- Waste kept in the neighborhood: burned or dumped
- Solidarity principle mostly absent

ISWM Framework



Source: MSWM-MOOC Sandec (2016)

Treatment – Mixed waste

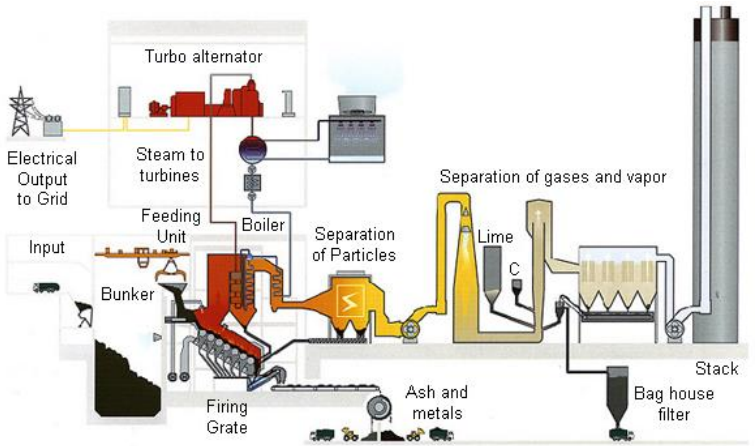
Energy valorisation through incineration

- Products: ash, gases, heat (either used directly or for producing electric power)
- Huge investments (> 400 million CHF)
- Highly qualified operational and maintenance personal
- Well developed logistic system (waste transport and energy transport)
- **Feasibility of incineration depends on waste characteristics (Lower Calorific Value)!!**

$$LCV\ [kcal/kg] = 40\ (a + b + c + d) + 90e - 46W$$

in % of wet weight:

a = Paper	*d = Food waste*
b = Textiles	*e = Plastic & Rubber*
c = Wood & Leaves	*W = Water*



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In LAMI countries, LCV is mostly lower than 1’000 kcal/kg!

For incineration without additional fuel at least **1’000 kcal/kg** (LCV) required

For incineration with energy recovery a LCV of a least **1'500 - 1'650 kcal/kg** is required

Disposal

Common practices

- Burning
- Illegal dumpsites
  - Within the municipality
  - Outside the municipality
- Negative impacts on health, hygiene & environment

→ Mostly uncontrolled and unorganized
→ Priority on disposal lacking! (out of sight, out of mind)

Disposal

Incineration

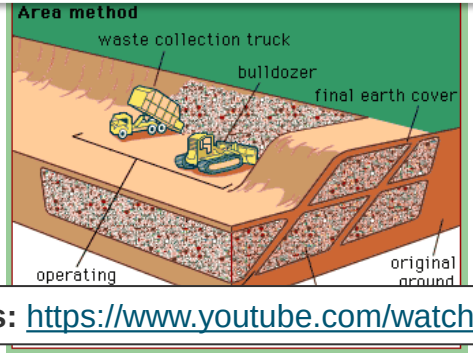
- Common practice with hazardous wastes (e.g. hospitals)
- Ovens. Often uncontrolled burning conditions.

Landfill

Three requirements:

1. Compaction of the waste
2. Daily covering (with soil or other material)
3. Control and prevention of negative impacts (e.g. leachate treatment + control emitted gases)

→ Fullfilling these requirements is expensive…



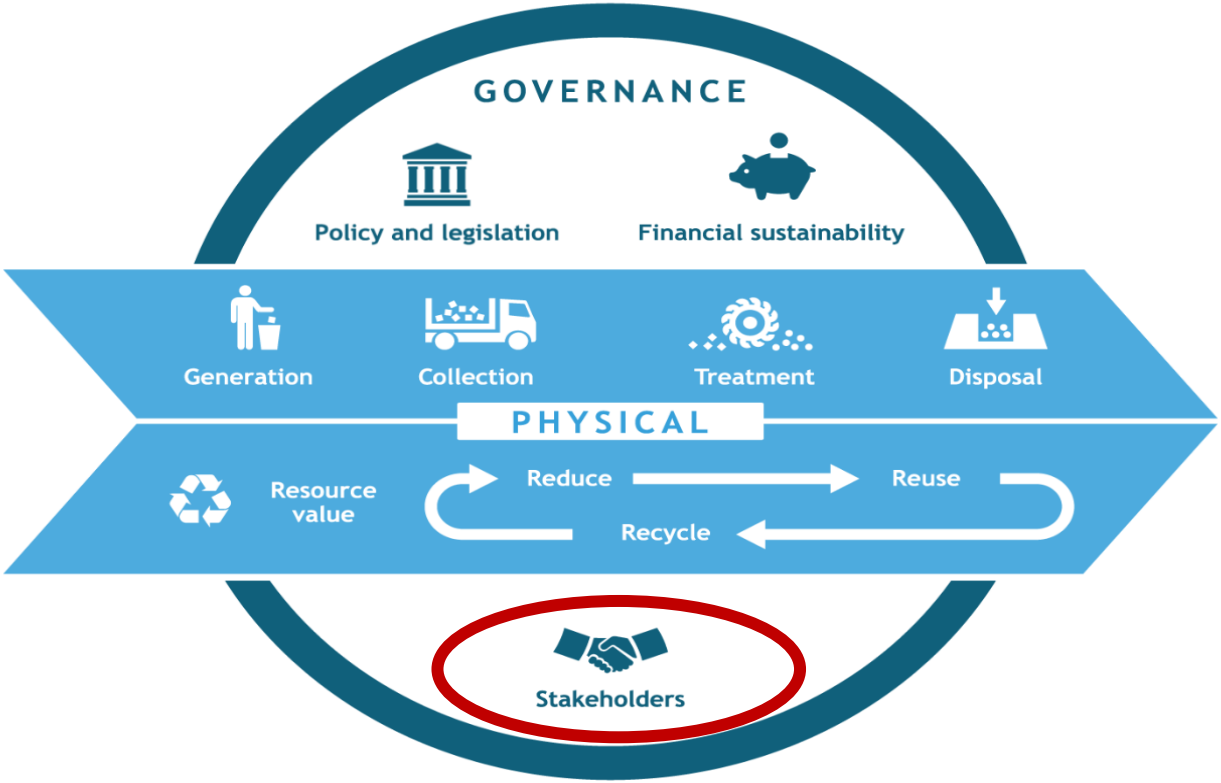
Upgrading dumpsites: https://www.youtube.com/watch?v=euFsNxPhVlY

Video – SWM disposal

What bad practices can you see in this video?


https://sbj.net/stories/waste-line-landfill-use-is-rising-with-population-development,82341

ISWM Framework



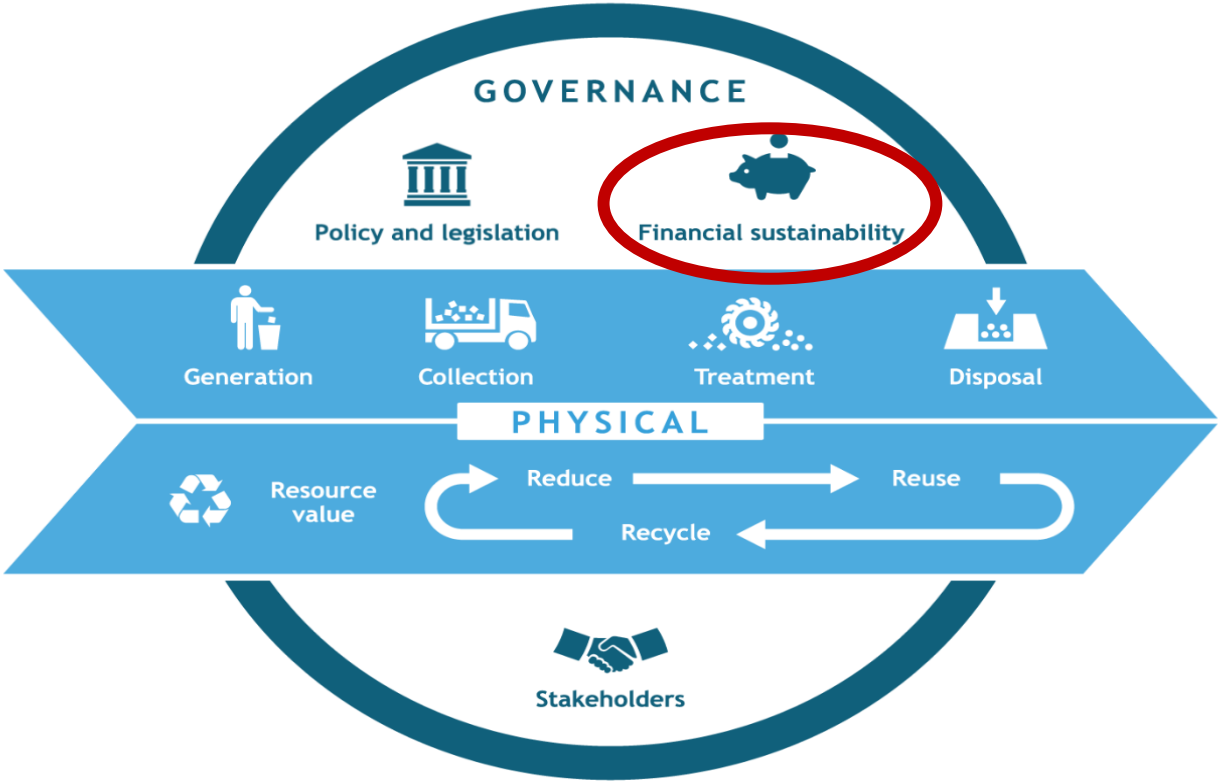
Source: MSWM-MOOC Sandec (2016)

Stakeholders

SWM can not be solved with technology or engineering alone.

- Waste generators — *Interface with the system (waste segregation?)*
- Central/provincial government — *Determine strategy, policy, regulation, commitments*
- Municipality — *Service provider and regulator*
- NGOs & CBOs — *Awareness and self-help initiatives*
- Private formal sector — *Provide service*
- Private informal sector — *Play an integral and important part in most low and middle income countries*
- Internal & ext. support agencies — *Support and steer through funding and international conventions*

ISWM Framework



Source: MSWM-MOOC Sandec (2016)

Financing sustainability

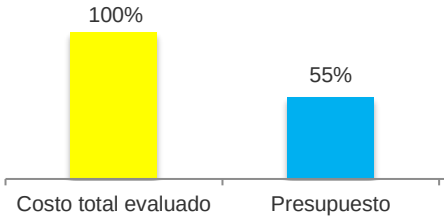
- **Costs for a good service**
  - Investment (CAPEX)
  - O & M costs (OPEX)
  - Externalities

- **Rarely known**
  - Multiple actors
  - No separate budget
  - Money used elsewhere

To be sustainable financially, a service should account for CAPEX and OPEX

Externalities are important to account for as long term costs also arrive from the impacts…

Example: Villa Montes - Bolivia



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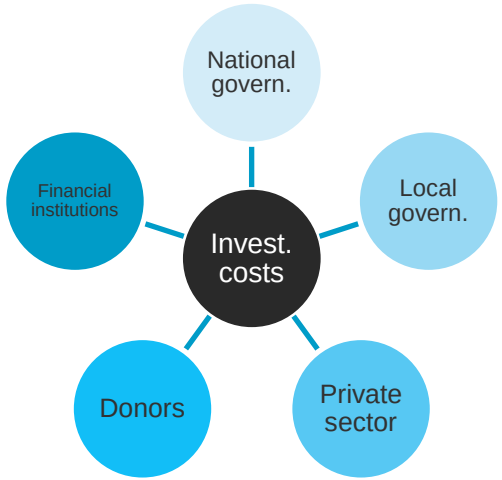
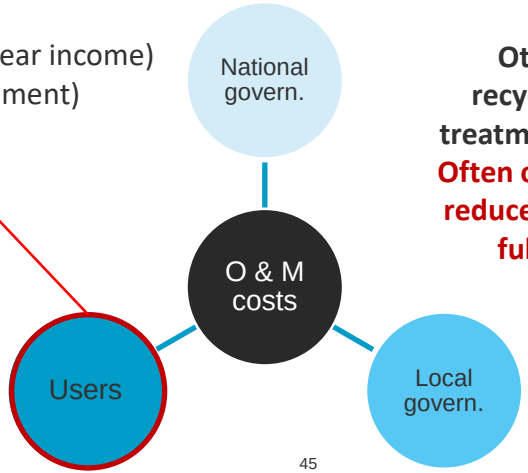
- **Most common revenue sources:**



Affordability of fees (<1% year income)
Willingness to pay (Enforcement)



Other revenues:
recyclable & organic treatment products sales
Often only contributes to reduce costs, it does not fully cover them

Financing sustainability

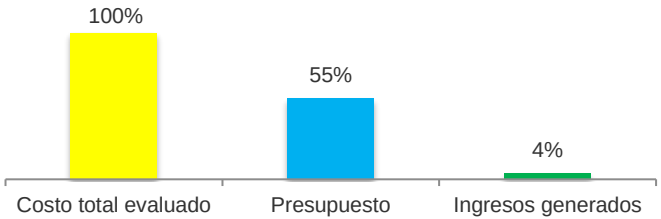
- **User charges**
  - Flat rate
  - Attached to other bills
  - Pays as you throw (PAYT)

- **Careful:**
  - Affordability of fees (<1% year income)
  - Willingness to pay (Enforcement)

COST RECOVERY

How much of the total costs do we want to cover/ can be covered through user direct fee?

Example: Villa Montes - Bolivia



Some costs for SWM

Table 5.2 Typical Waste Management Costs by Disposal Type

US$/tonne

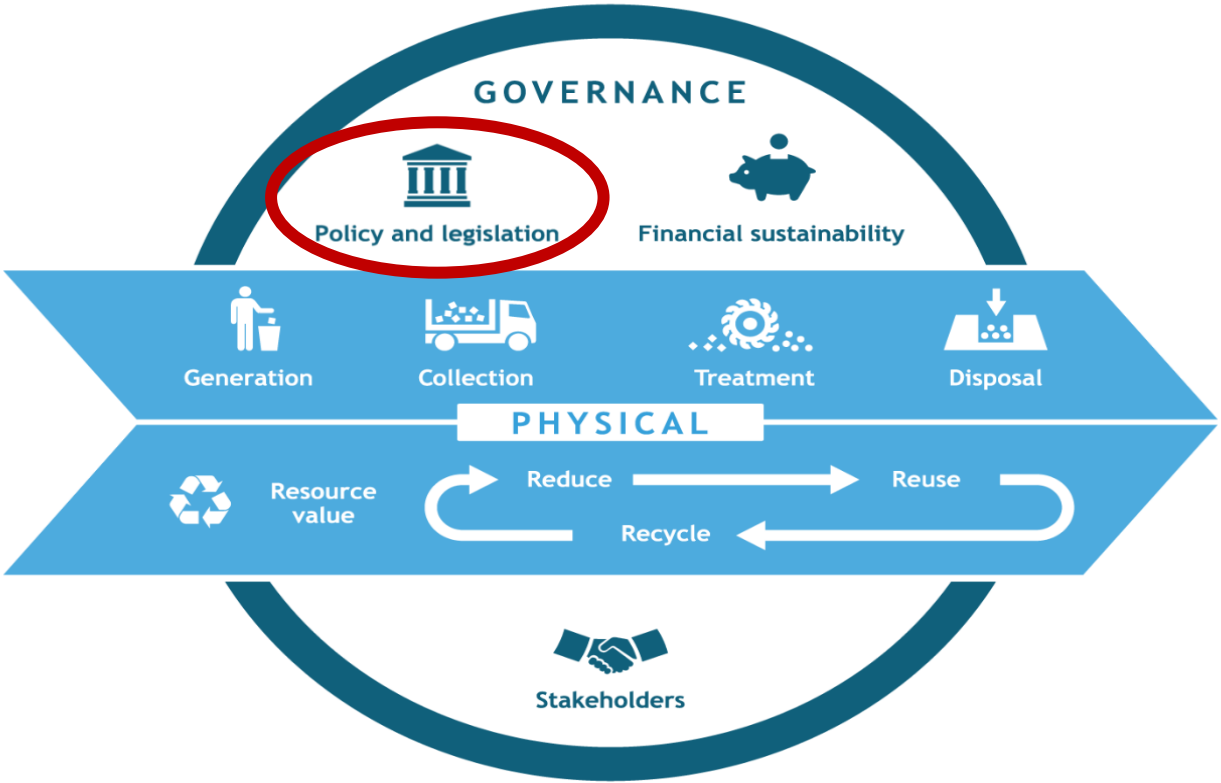
	Low-income countries	Lower-middle-income countries	Upper-middle-income countries	High-income countries
Collection and transfer	20–50	30–75	50–100	90–200
Controlled landfill to sanitary landfill	10–20	15–40	20–65	40–100
Open dumping	2–8	3–10	—	—
Recycling	0–25	5–30	5–50	30–80
Composting	5–30	10–40	20–75	35–90

Source: World Bank Solid Waste Community of Practice and Climate and Clean Air Coalition.

Note: — = not available.

WorldBank (2018). What a waste 2.0 : A global snapshot of solid waste management to 2050.

ISWM Framework



Source: MSWM-MOOC Sandec (2016)

Policy and legislation

- **Bottom line:** Protection of human health and the environment
- **Definition of responsibility:** Local governments, as “proxy-waste generators”
- **Challenges: Policies and strategies need to be enforceable**
  - Legitimacy, political support
  - Institutional capacity
  - Financing

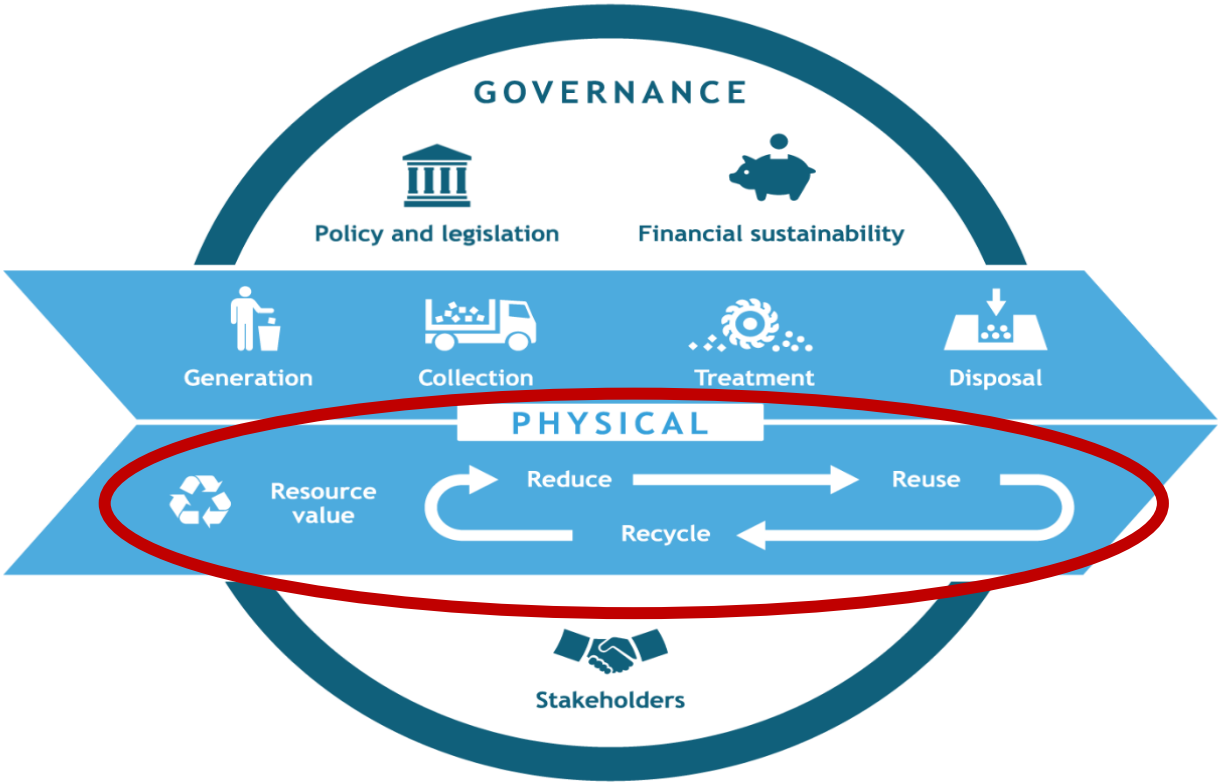
Waste hierarchy

https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

Policy and legislation: Interesting case of plastic ban

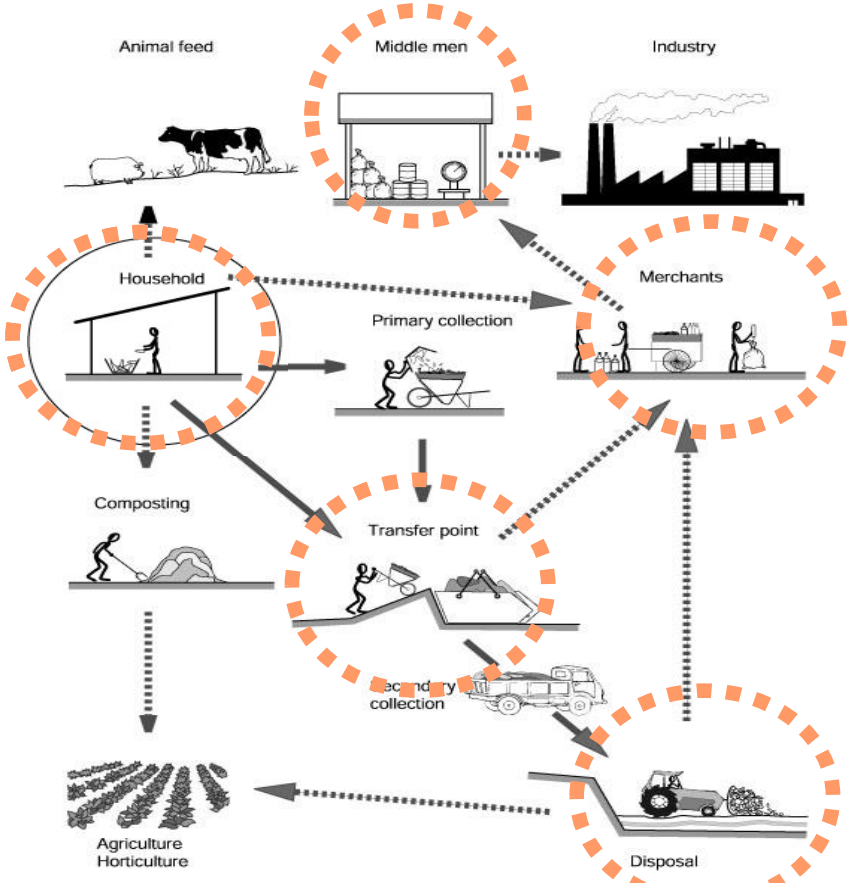
→ Is it replaced by another material? Is it actually better?
→ For example biodegradable plastics, or paper?
→ Condiser LCA & waste management capacities to take informed decisions

ISWM Framework



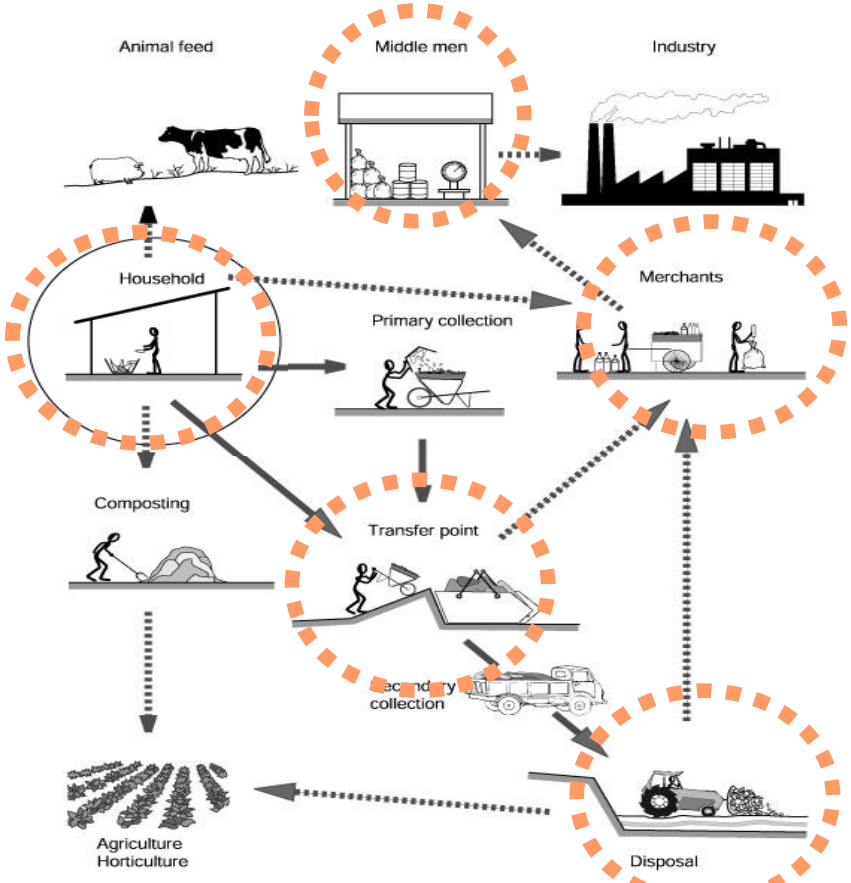
Source: MSWM-MOOC Sandec (2016)

Recycling system



- Separation of recyclables happens at many different steps of the system.

Recycling system



- Separation of recyclables happens at many different steps of the system.
- Recyclables collected further along the waste cycle worsens working conditions.
- Collection of recyclables is a function of market. It is not yet driven by concern of resource depletion.
- Two types of collection of recyclables:
  - **Informal**: Scavengers, waste pickers.
  - **Formal**: official businesses, companies


What are they extracting from the waste? What risks are they exposed to?

Recycling system – Informal sector

- Informal waste-pickers (known as scavengers) play an important role in solid waste management systems
- They collect from the streets, dumpsites, or landfills

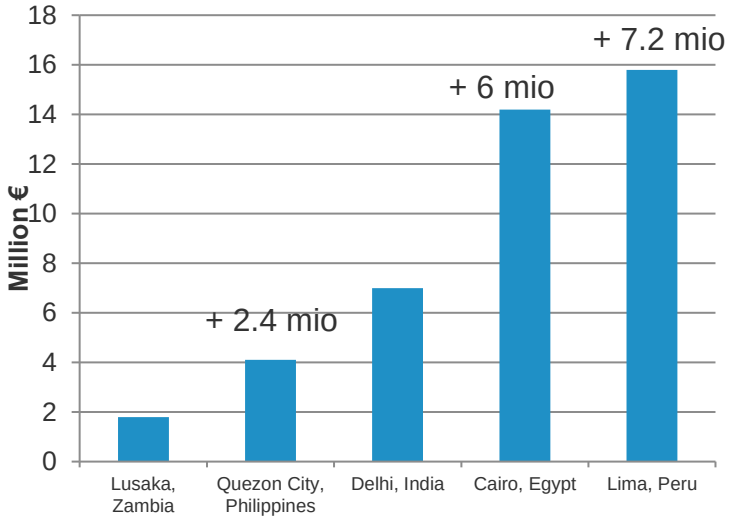
Scavengers in Son La, Vietnam

Recycling system – Informal sector

- Informal waste-pickers (known as scavengers) play an important role in solid waste management systems
- They collect, from the streets, dumpsites, or landfills
- Despite the benefits that they generate, **waste-pickers are ignored** when waste management policies are formulated.

- Cost savings:
  - Savings in collection and transport
  - Saving in space and landfill

- Savings due to recovered raw material



Recycling system – MOOC video

https://www.coursera.org/learn/solid-waste-management/lecture/CyQPX/1-6-recycling-municipal-waste

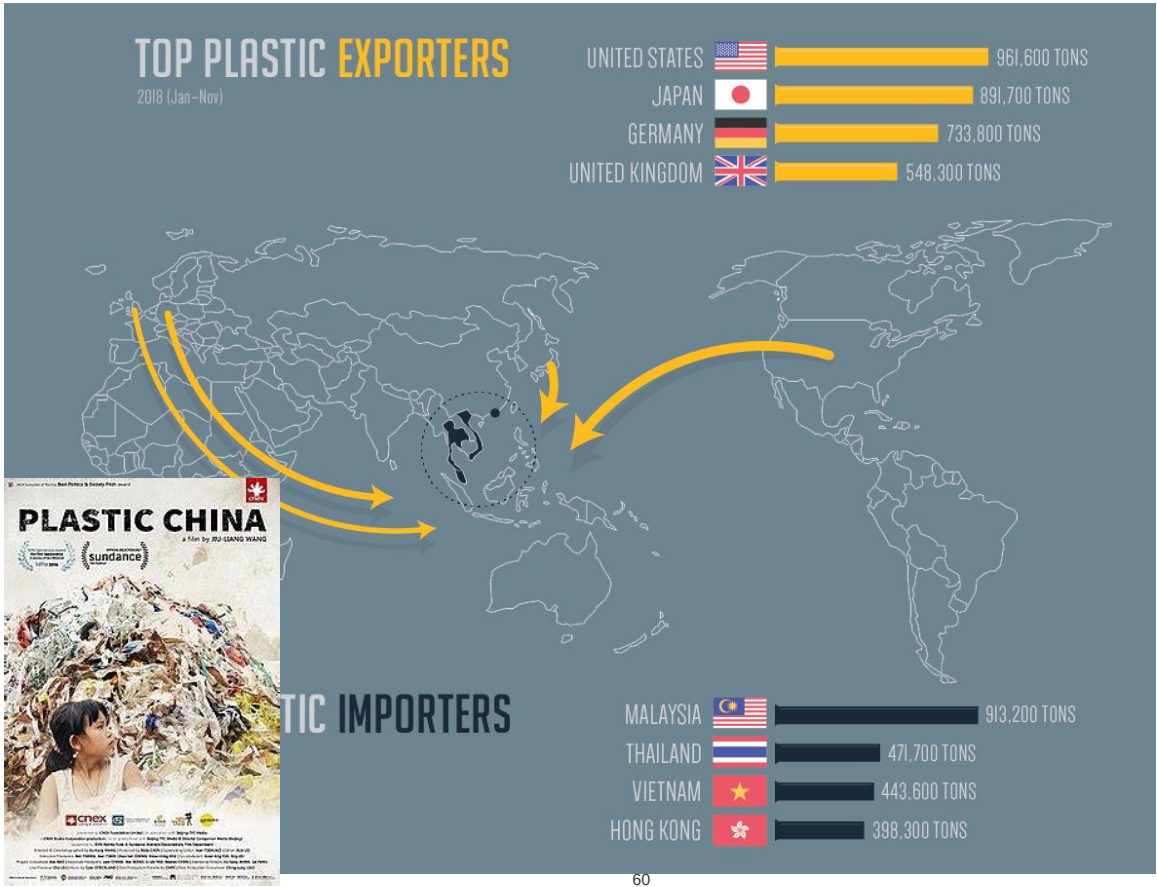
https://www.youtube.com/watch?v=bxF3-wdxUKk&list=PLNG_YQG6XtkWVi2lu6cMtnZ86Q6v8RM7A&index=6

→ Recycling Processes: Look at MOOC Modules 1.6 (coursera or Youtube)

Recycling system – Export Worldwide

Plastic export worldwide

- Wide range of plastic types!
- Not all easily recyclables…
- Handling the responsibility
- Driven by costs
- Global/transboundary issue – regulated under the Basel Convention
- 2018 China banned most plastic imports -> huge change on the market
- Short read on the topic: https://blog.cleanhub.com/plastic-waste-exports

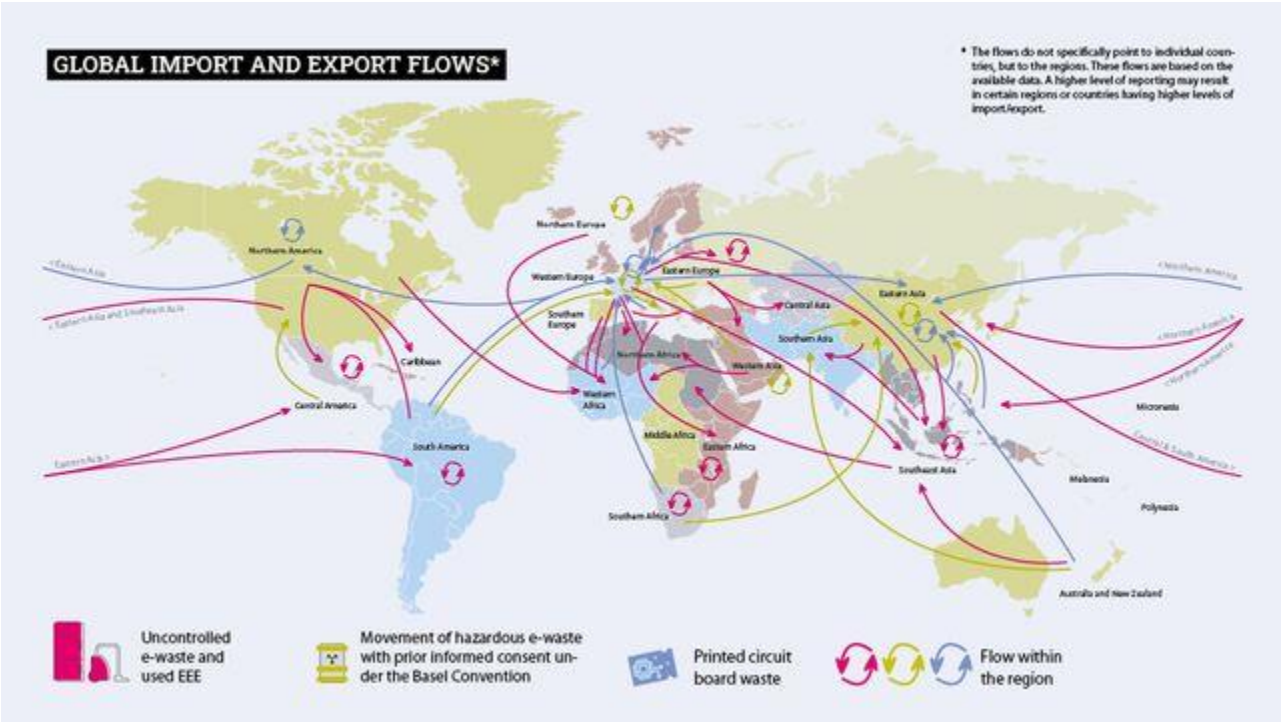


Recycling system – Export Worldwide

E-waste export worldwide

- Small amounts but big impacts!
- High income: 1% of MSW
  LAMIC: 0.01-1% of MSW
- > 1000 different substances
- Global/transboundary issue

https://www.youtube.com/watch?v=4DFjA2Y1RXU



https://waste-management-world.com/materials/global-e-waste-flows-monitor/

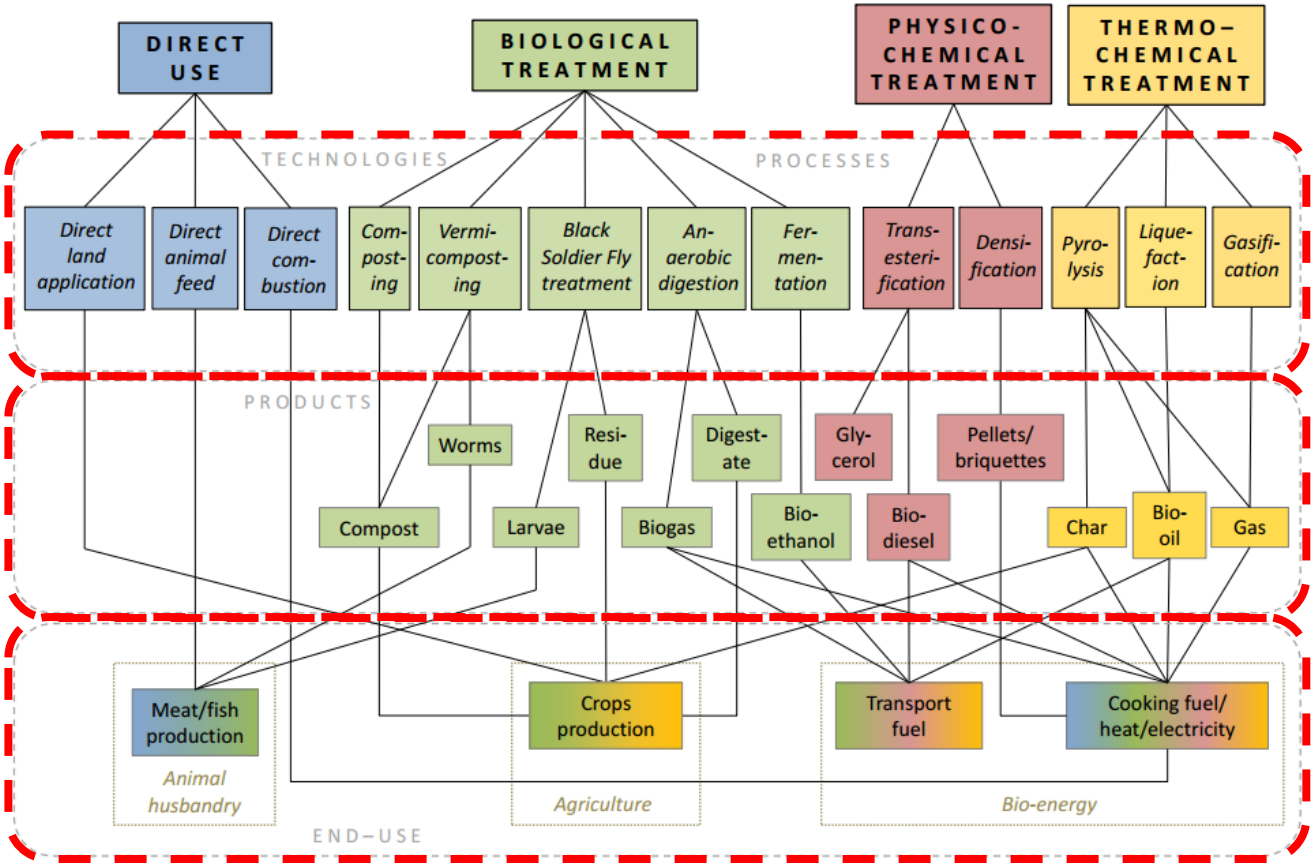
Organic Waste Treatments

What problems can organic waste cause?

- Health threats
  - Hygiene
  - Pest attraction
- Environmental threats:
  - Methane emissions
  - Ground water pollution

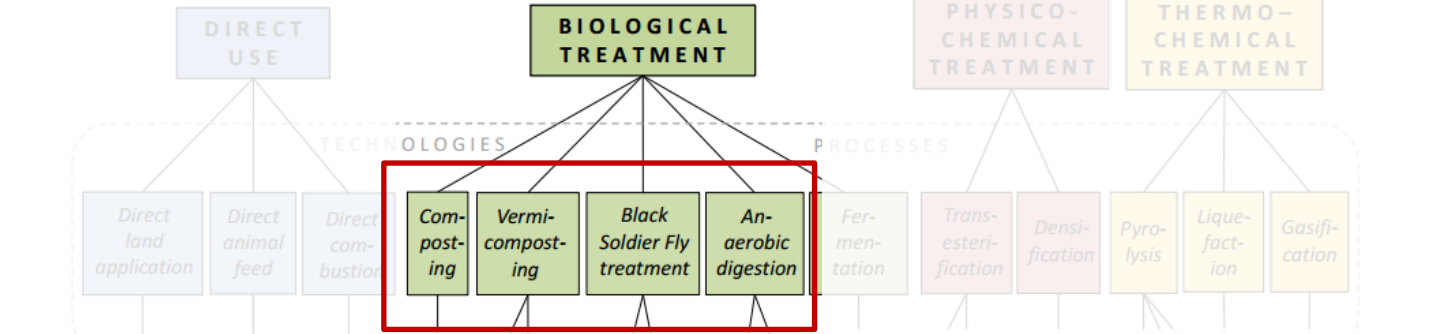
- High moisture
  - High density which affects collection and treatment options.
  - Corrosion of equipment
  - Not suitable for incineration (low heating value)
  - Contaminate other materials → Organic wastes diminishes the quality and value of other recyclables.

Organic Waste Treatments



Lohri et al. 2017. *Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings*

Organic Waste Treatments



Composting

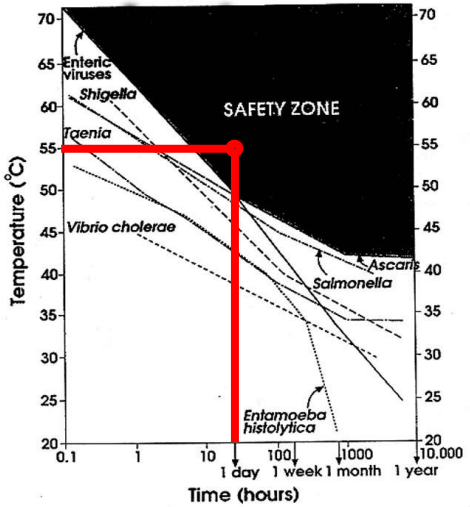
Anaerobic digestion

Black Soldier Fly

Composting & Vermicomposting

- Compost is generated when **aerobic bacteria and invertebrates** decompose organic matter.
- **A simple approach**
- Compost is a stable humic material, used as soil conditioner → benefits
- Hygienization: heat is a very effective way of killing pathogens

- **Vermicomposting** results in add value product



Some treatment data	
Moisture	40-60%
C/N of waste	20-50 (opt. ~25)
Water needs	10-70 L/ton
Waste reduction (dry basis)	25-50%

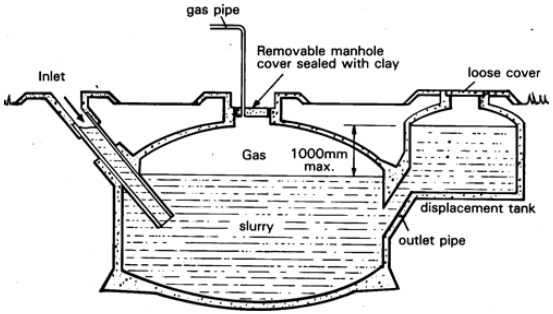
Windrow composting in Bolivia

Bin composting in Bangladesh

Anaerobic Digestion/Biogas

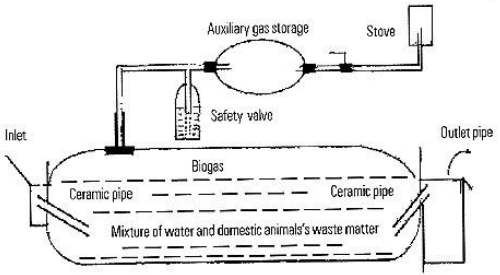
- Biogas is generated when **anaerobic bacteria** decompose organic matter (no oxygen)
- Most commonly used system: Mesophilic (25-35°C) wet system (5-16% TS)
- Products:
  - **Biogas: energy**
    - 40-70% Methane
    - 30-60% CO_2
    - 1-5% other gases
  - Digestate: fertilizer

- Different types of digesters:
  Fixed dome/ Floating dome/ Baloon



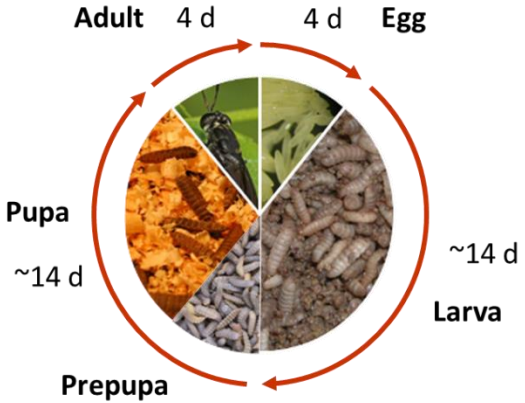
Some treatment data	
Moisture	60-95%*
C/N of waste	16-25
Water needs	0 - 5,000* L/ton
Waste reduction (dry basis)	0 - 25%*

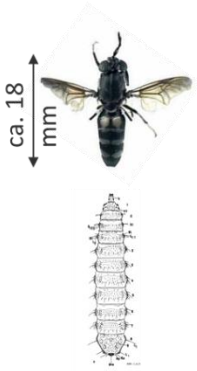
*Depends on system



Black Soldier Fly, *Hermetia illucens*

- Organic waste is eaten by growing larvae under **aerobic conditions**.
- Larvae develop and are harvested before pupation
- Products:
  - Larvae, contain 40% crude protein and 30% of fat, can be processed and **replace fishmeal** in animal feed
  - Residue, contains valuable nutrients and can be used as soil amendment after maturation phase





Some treatment data	
Moisture	70-80%
C/N of waste	Non-influential
Water needs	Depends
Waste reduction (dry basis)	50-80%

The larvae feed on organic matter:

- Slaughterhouse waste
- Animal manure
- Food and market waste
- Human excreta

Waste reduction

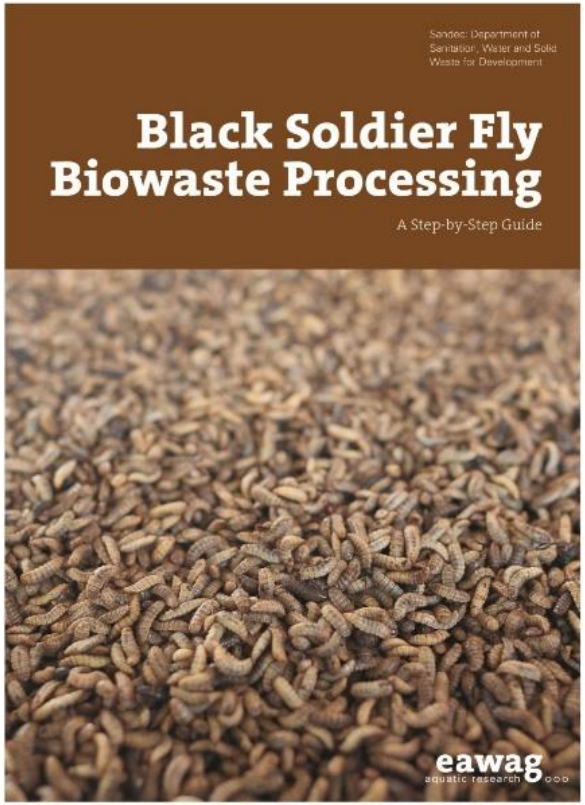
Larvae are rich in proteins and fat

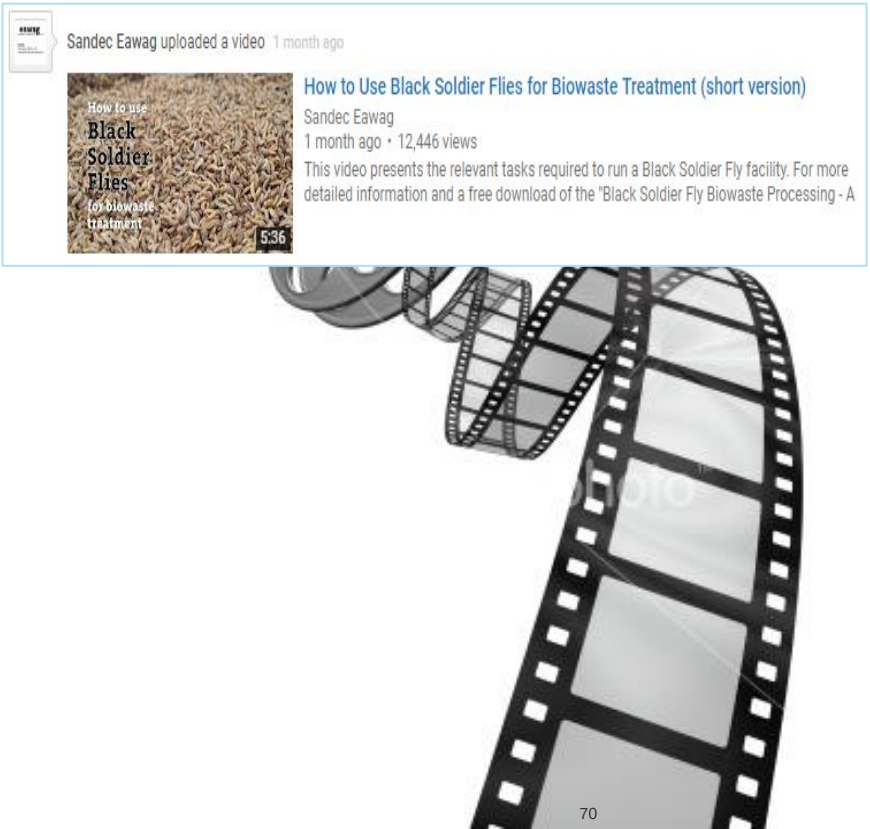
Can substitute fishmeal in animal feed

The adults don't eat

Minimized risk of disease transmission

Black soldier fly (BSF) treatment technology





Organic Waste Treatment Technologies

How to chose adequate treatment option?

Organic Waste Treatment Technologies

How to chose adequate treatment option?

Important criteria:

- Waste type to be treated
- Market demand and value for the end-product
- Current legislation
- Climate
- Space available
- Material and knowledge available
- Financing situation: Investment + Operation and Maintenance

Organic Waste Treatment Technologies

How to chose adequate treatment option?

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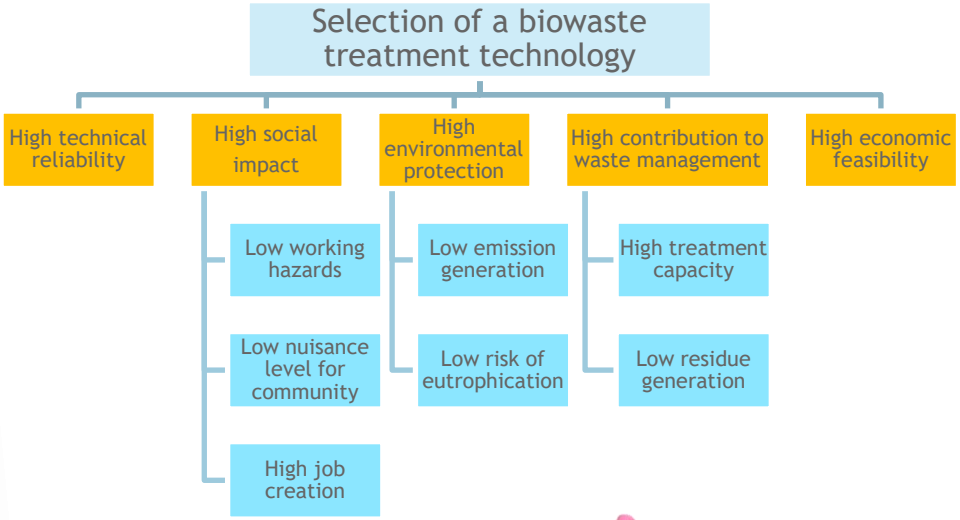

Take home messages

- Management of MSW is one of the major challenges worldwide, particularly in low and middle-income countries.
- Inadequate collection, recycling or treatment and uncontrolled disposal of waste in dumps lead to severe hazards, such as health risks and environmental pollution
- The amount of waste generated is often linked directly to income level and lifestyle
- There is no one-size-fits-all solution to the SWM challenge
- The socio-economic, cultural and institutional context in the developing world requires special consideration of appropriately adapted technologies, capacity building, including improvement of skills and know-how at local government level
- The ISWM framework is a structured assessment method to understand and find solutions to existing SWM systems.
- Recovery of resources (materials and energy) is a promising way to go in solid waste management (e.g. valorization of the organic fraction)

The best way to manage waste is to stop producing it

Thanks for your attention!

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Key Readings

- Wilson et al. (2013) Integrated sustainable waste management in developing countries
- Wilson et al. (2014) 'Wasteaware' benchmark indicators for integrated sustainable waste management in cities
- UNEP & ISWA (2015) Global Waste Management Outlook
- UN Habitat (2010): Solid Waste Management in the World's Cities. Earthscan.
- Abubakar, E. and Bello, M. (2006): Municipal Solid Waste Management: Options for Developing Countries, IPAC Technical Meeting. EEMS Limited, Kaduna, Nigeria.
- UNEP (2005): Solid Waste Management, CalRecovery Inc, 524 pp.
- Cointreau-Levine, S. and Coad, A. (2000): Private sector participation in municipal solid waste management - Guidance Pack. SKAT, St. Gallen, Switzerland.
- Lohri et al. (2017). Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings
- WorldBank (2018). What a waste 2.0 : A global snapshot of solid waste management to 2050.
- UNEP (2024). Global Waste Management Outlook 2024. Beyond an age of waste Turning rubbish into a resource.

► Further publications: www.sandec.ch

► MOOC: https://www.coursera.org/learn/solid-waste-management/lecture/CyQPX/1-6-recycling-municipal-waste