SOLID WASTE MANAGEMENT in low- and middle-income countries

EPF Lecture

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Sandec, Eawag

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, Costa Rica, Nicaragua, Panama, Honduras, Dominican Republic, El Salvador, Uganda, Vietnam.

Project manager – Scientist at Sandec

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Outline of the lecture

Learning Objectives

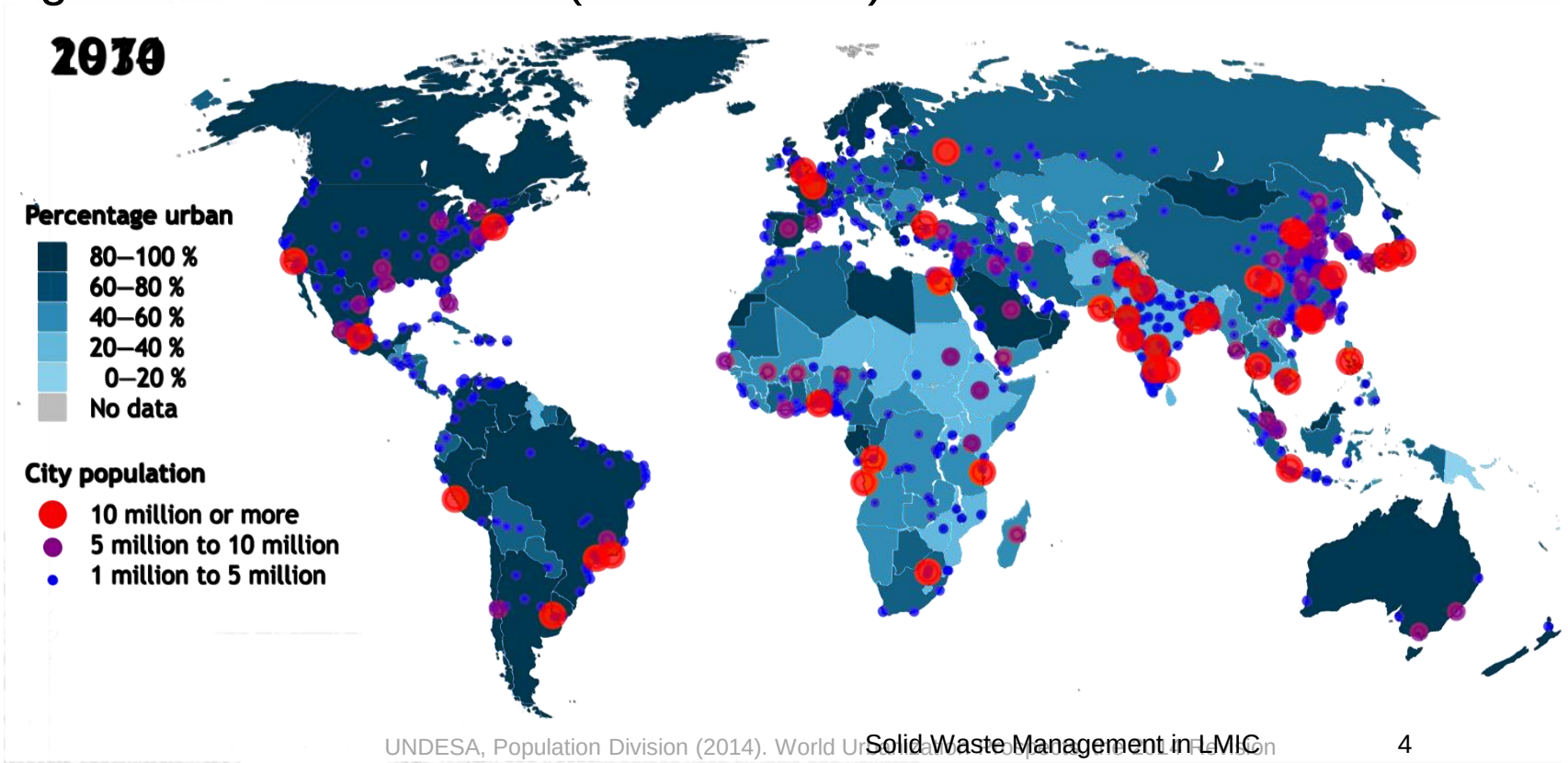
- **Challenges and Situation** → *Evaluate appropriate solutions in the solid waste management chain within the context of low- and middle-income countries*
- **Definitions and ISWM Framework** → *Identify the key physical and governance elements of a Solid Waste Management System*
  - Physical elements
  - Governance aspects
- **Recycling & Organic waste treatment technologies** → *Distinguish between different organic waste treatment technologies and compare their suitability for various settings*
  - 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 (and industrial) growth
- Migration to urban areas (urbanization)
- Lack of sufficient funds and affordable services
- Low-skilled labor force

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

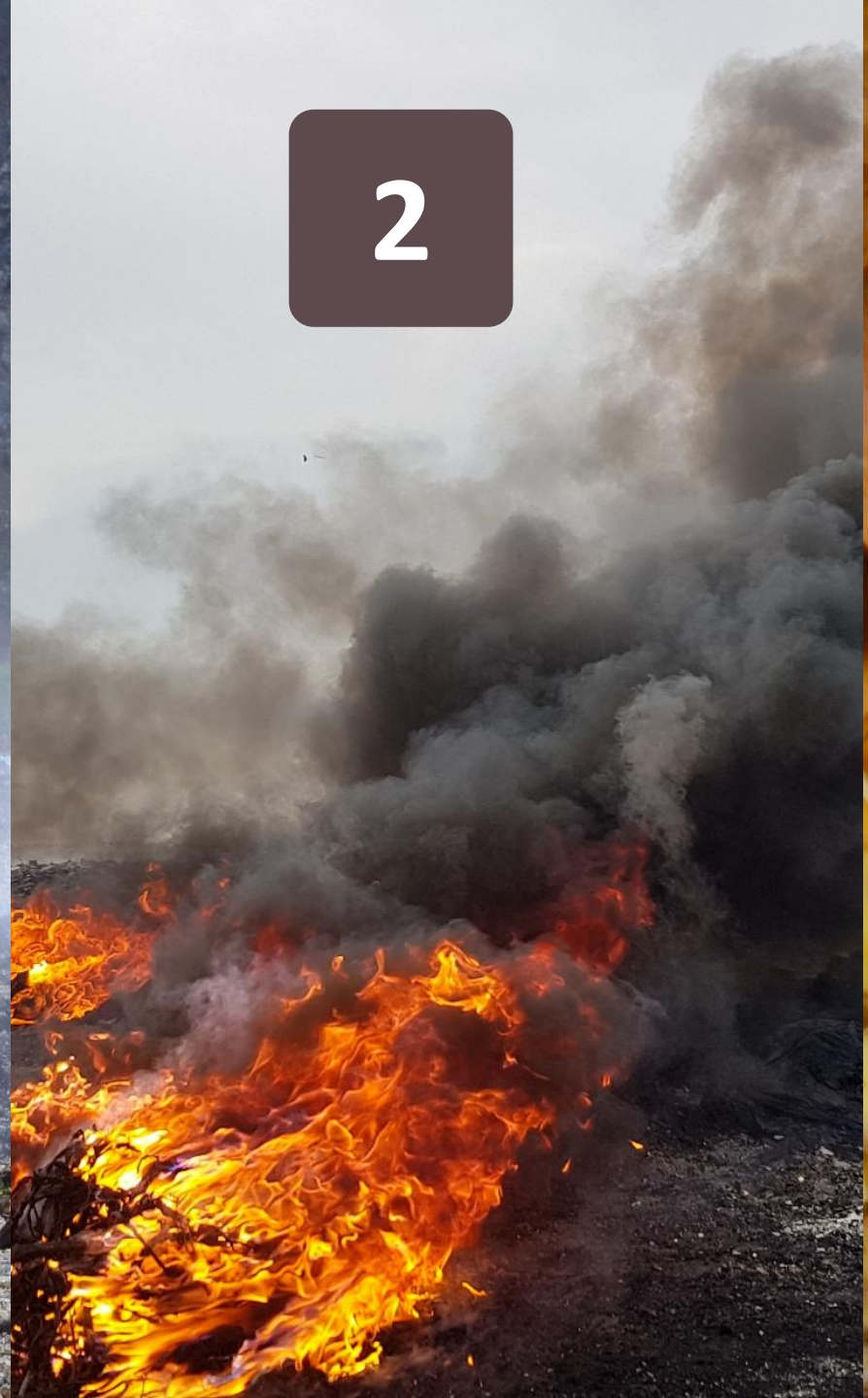
Neighborhood dump, Mumbay, India

Informal sector in Cochabamba, Bolivia

Your turn:

What are impacts of improper waste management?


1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3

1 Environmental Threats

Greenhouse gas emissions

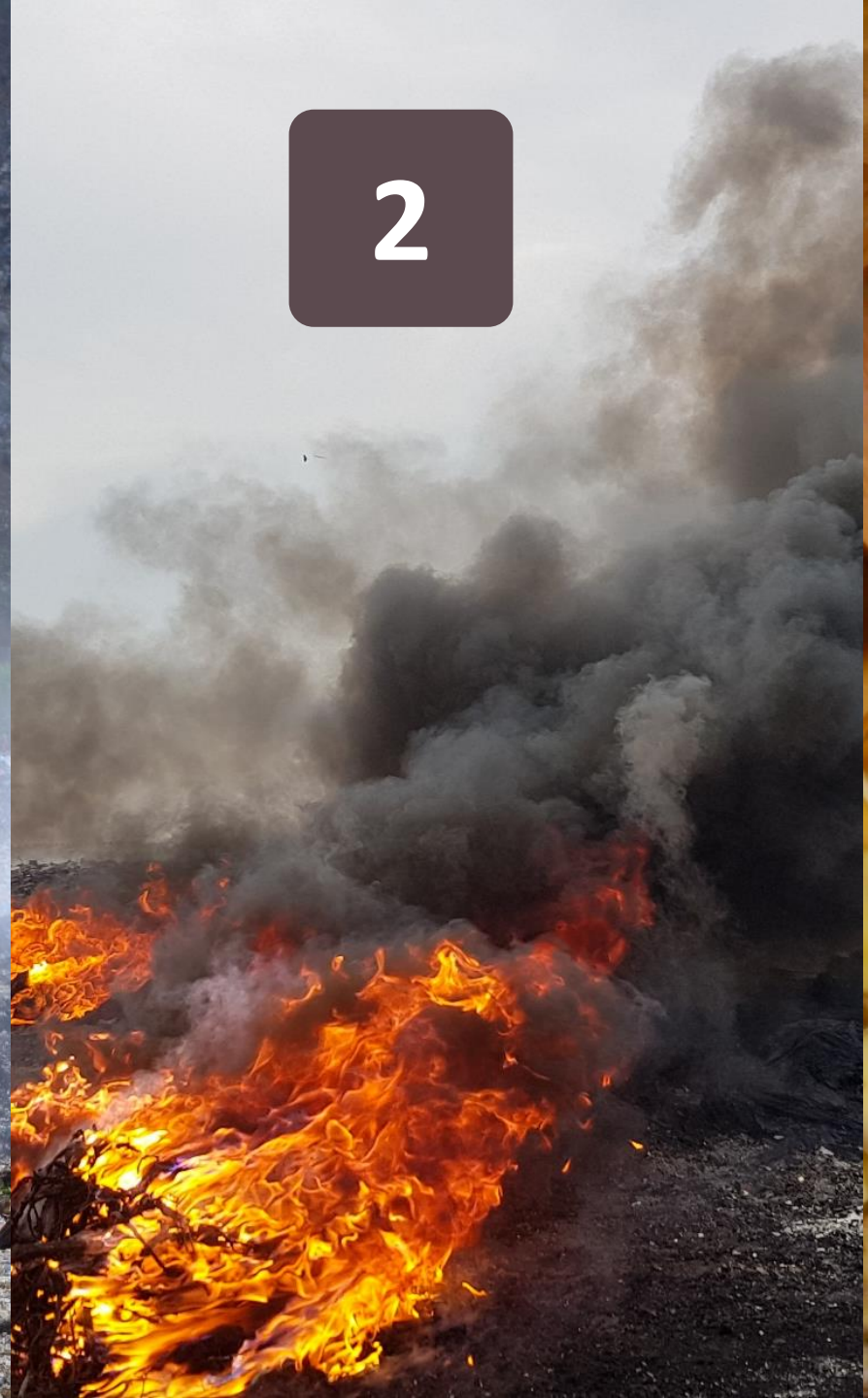
1 Environmental Threats

(Ground)water pollution

1 Environmental Threats

Blockage of drainage system


1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3

2 Health Threats

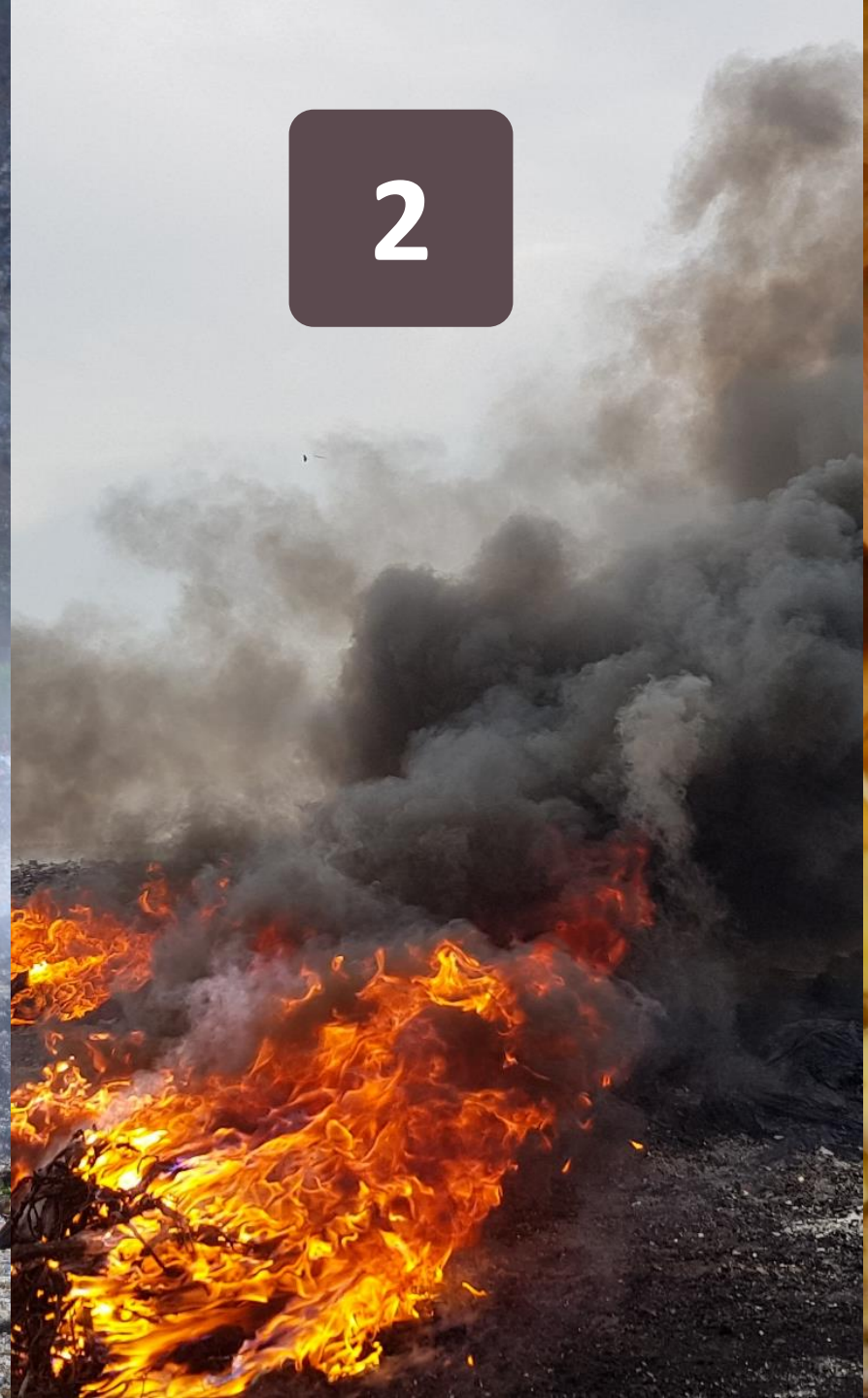
Respiratory problems

Black carbon emissions

2 Health Threats

Attract pests and rodents


1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3

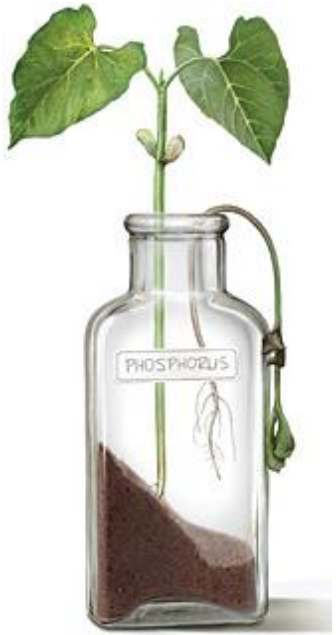
Resource Depletion

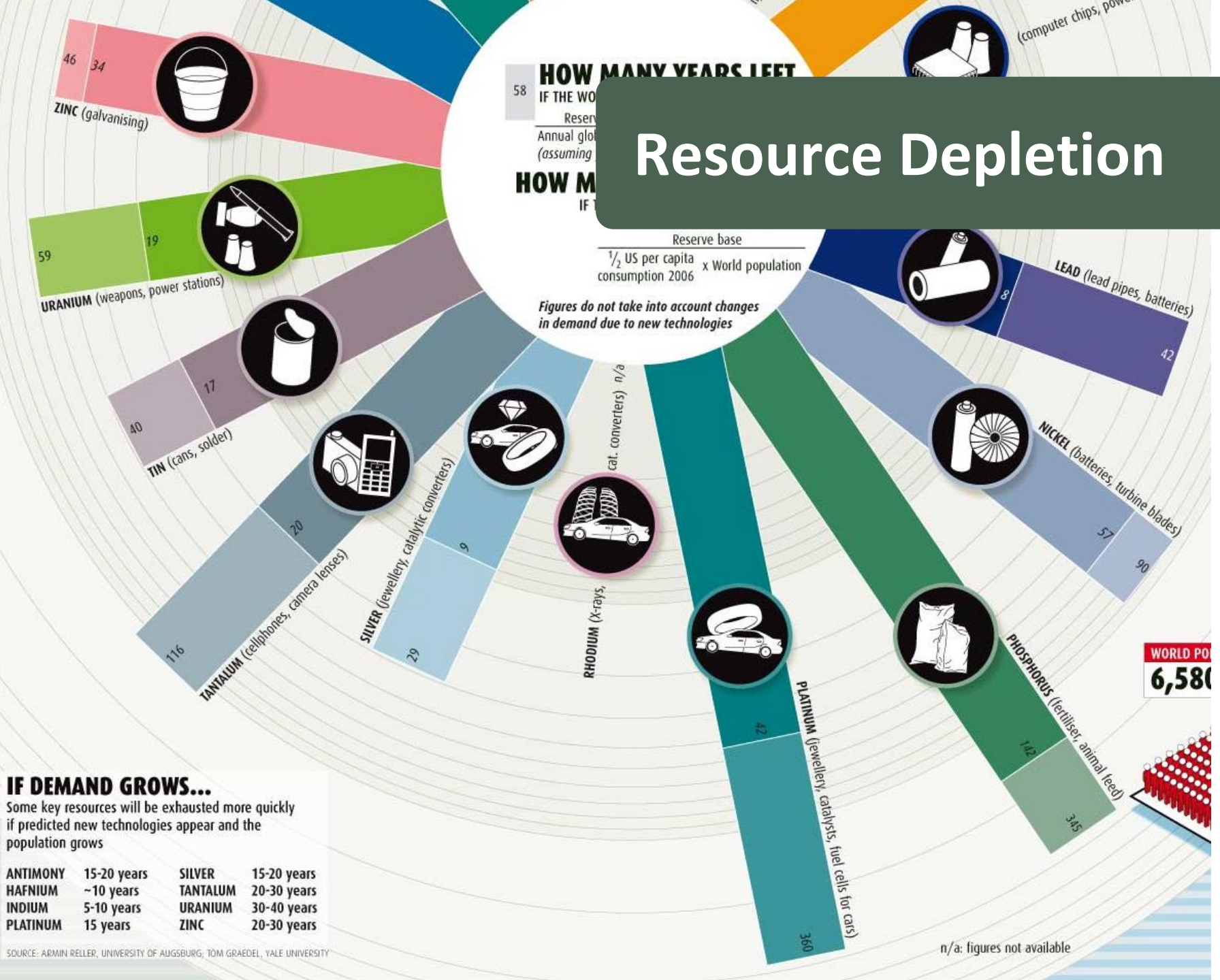
3

Loss of nutrients

Resource Depletion

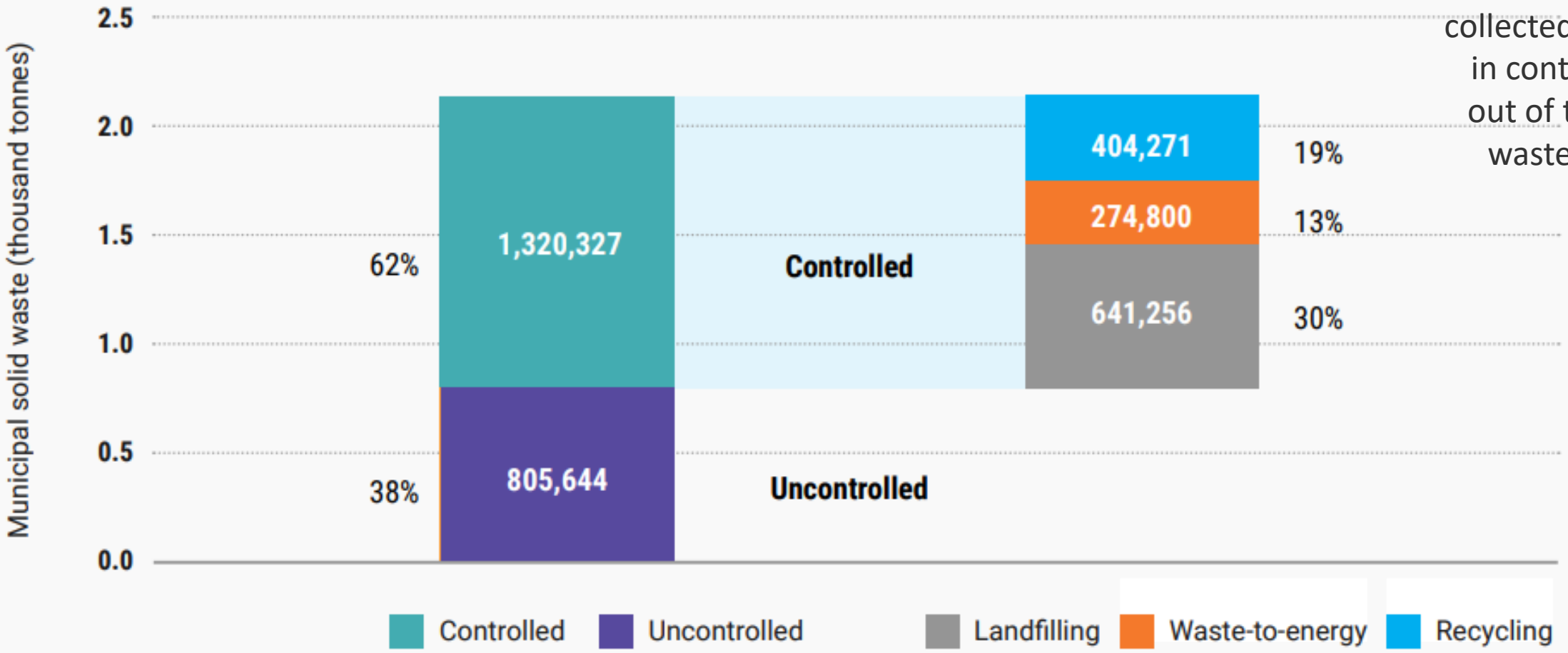
3





Current situation

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



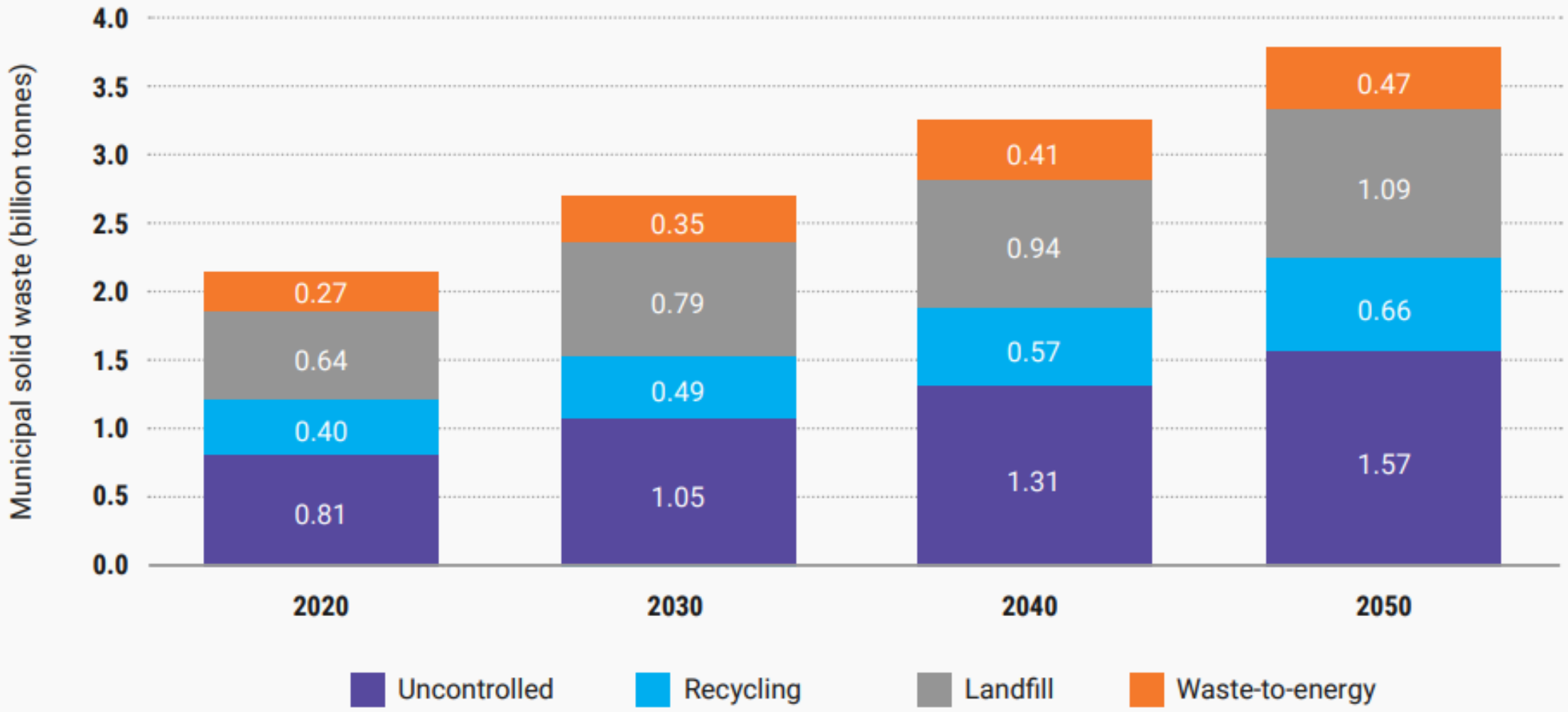
SDG Indicator

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

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

Expected situation

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

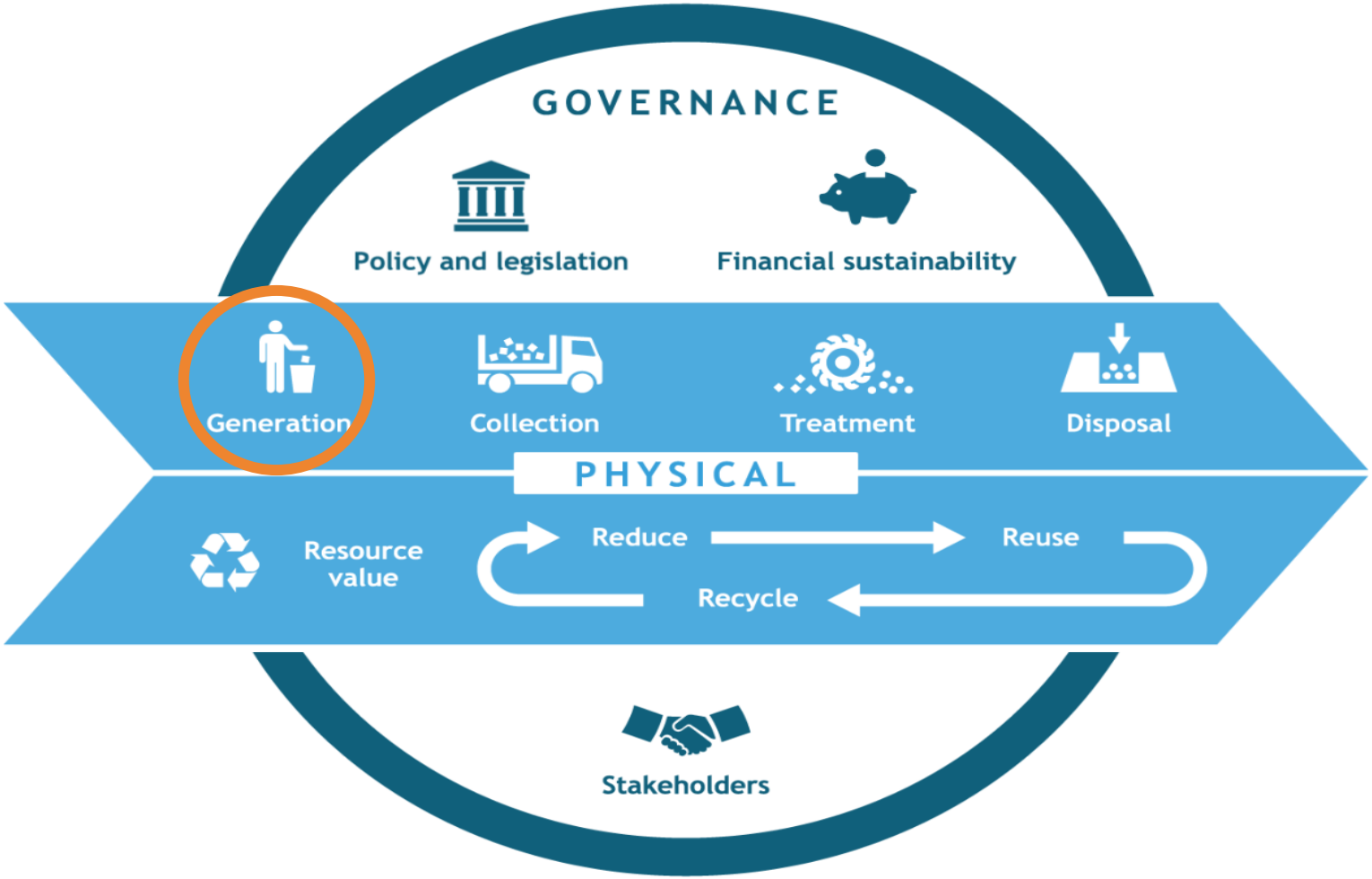


UNEP (2024). Global Waste Management Outlook 2024. Beyond an age of waste Turning rubbish into a resource.

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)

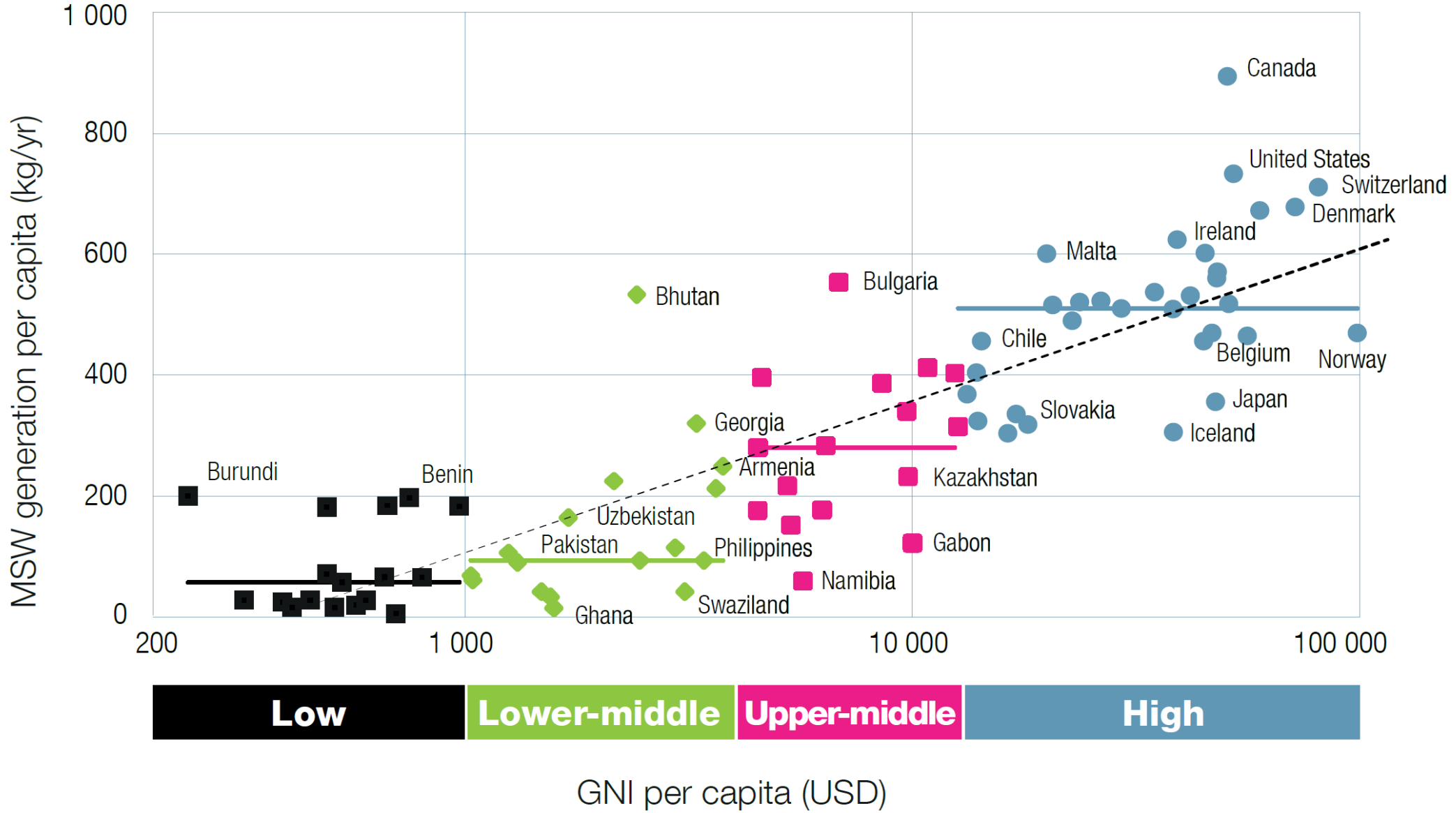
Generation

Two important aspects:

a) MSW generation:

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

Generation


1 000
800
600
400
200
0
MSW generation per capita (kg/yr)
200
1 000
10 000
100 000
GNI per capita (USD)
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
Low
Lower-middle
Upper-middle
High

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)

Generation

Waste Fractions

Recyclables

PLASTIC

CARDBOARD & PAPER

METAL

GLASS

OTHER

Organics

Residual

Generation

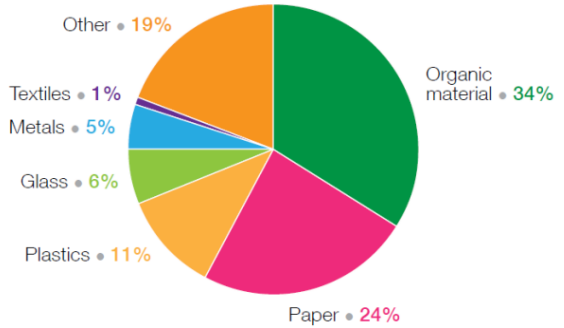
Two important aspects:

a) MSW generation:

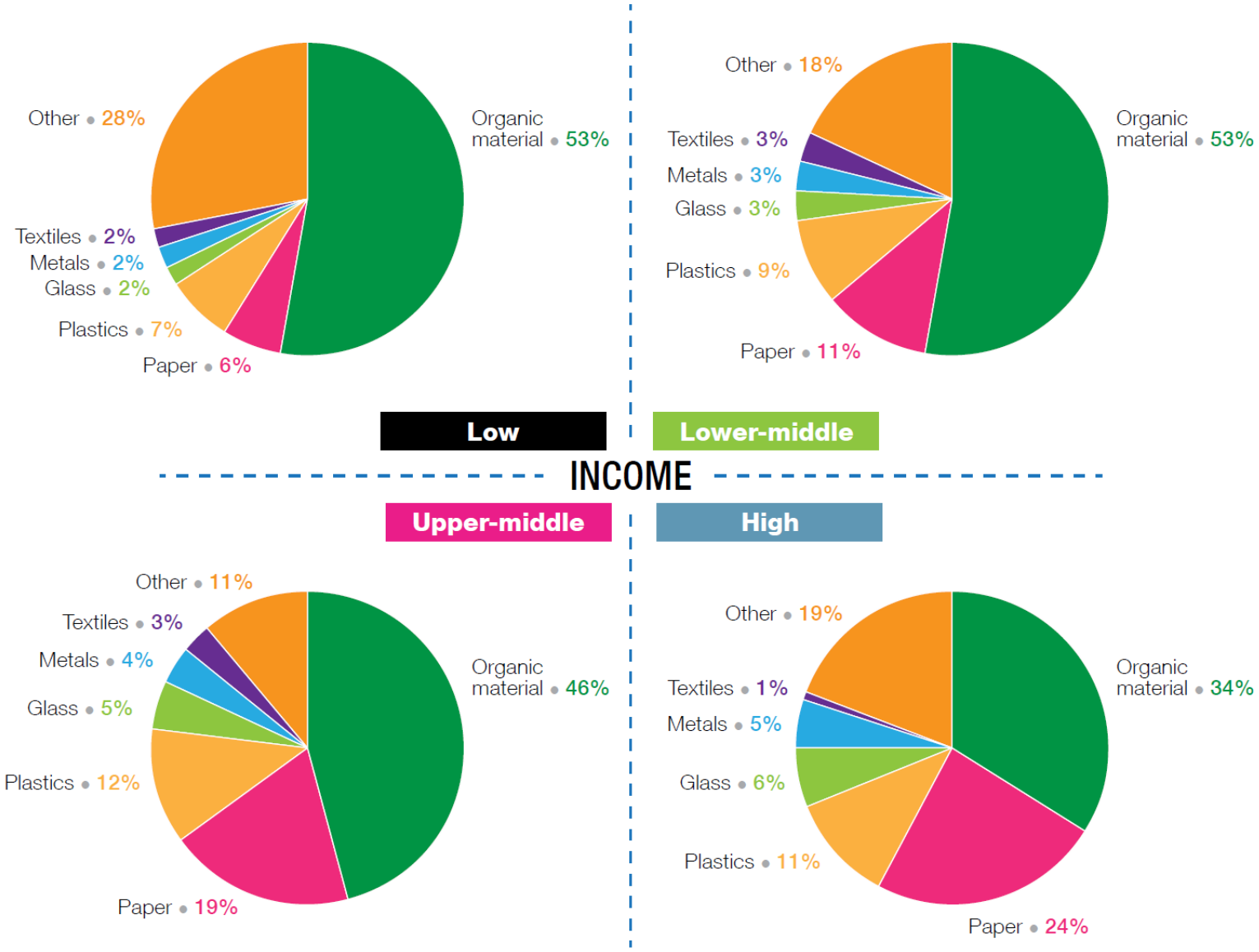
	Lahore (Pakistan)	Guadalajara (Mexico)	Belfast (Northern Ireland)
ton/year	1’916’000	2’000’000	149’000
kg/year per capita	219	440	683
kg/day per capita	0.6	1.2	1.9

b) Characterization: MSW composition (% of mass)

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



Generation


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

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/m³	250–500	170–330	100–170
Water content	%	40–80	40–60	20–30
Composition				
Organic		40–85%	20–65%	20–50%

(Cointreau, 1982, in Zurbrügg, 2003)

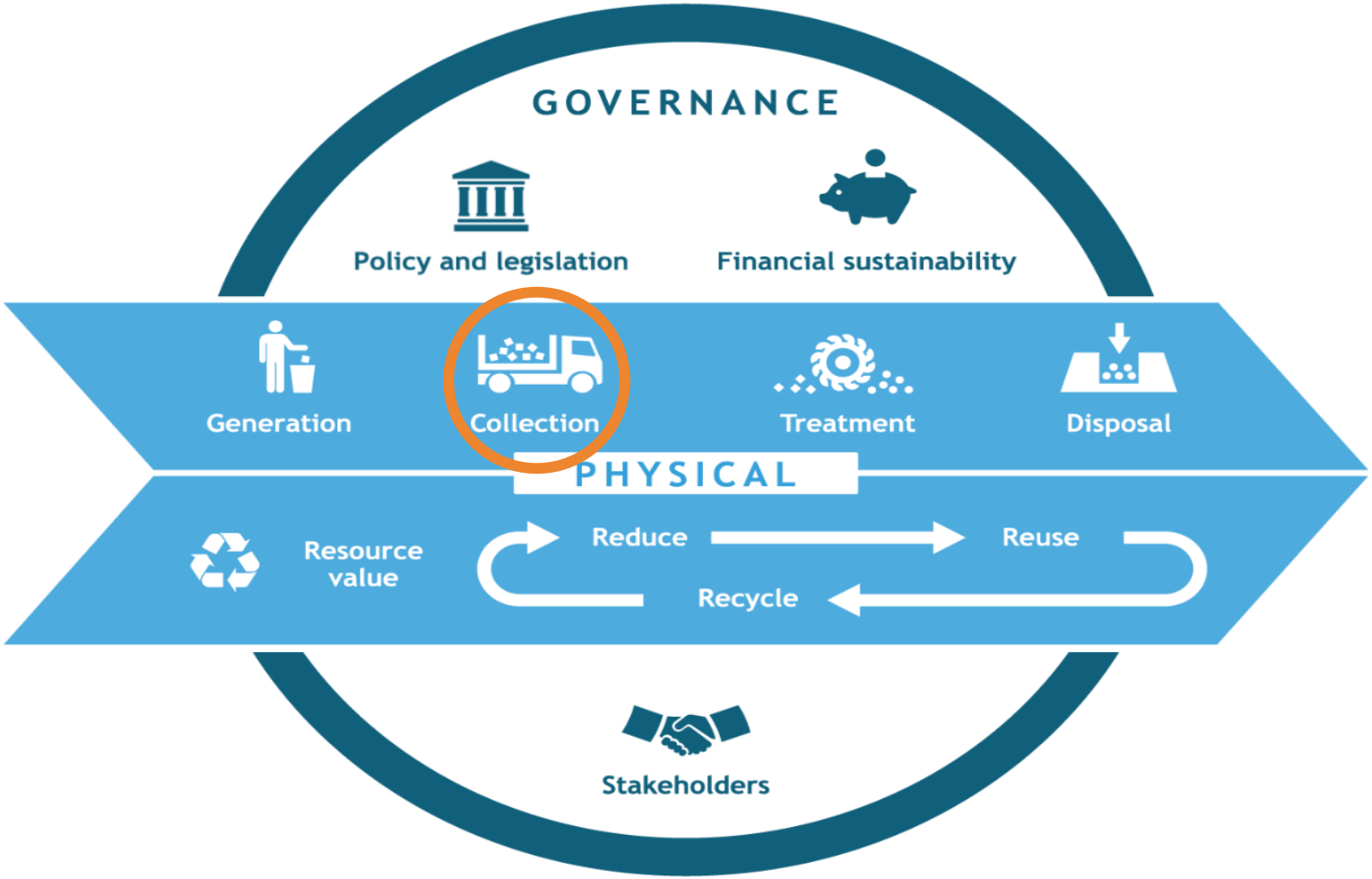
Low-income: GDP < US$ 360 per year per capita
Middle-income: GDP > US$ 360 per year per capita.
High-income: < US$ 3'500 per year per capita.

For low-income settings
- Low amounts
- High density
- High organics and wet

Important for:

- Policy and measures
- Waste collection system
- Treatment and disposal options

ISWM Framework

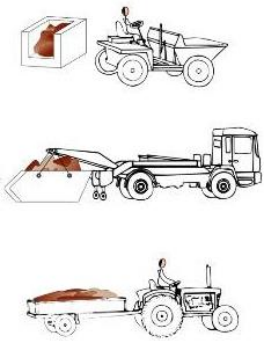


Source: MSWM-MOOC Sandec (2016)

Collection and Transport

How does it work?

Generation → Primary collection → Transfer station → Secodnary collection



Bangalore, India (Sandec)

Pentakatha, India (Sandec)

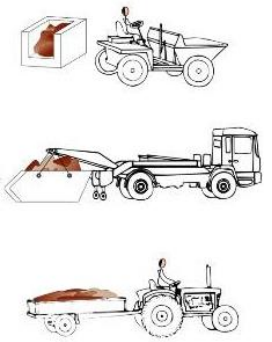
Collection and Transport

How does it work?

Generation

Waste collection in Colombia

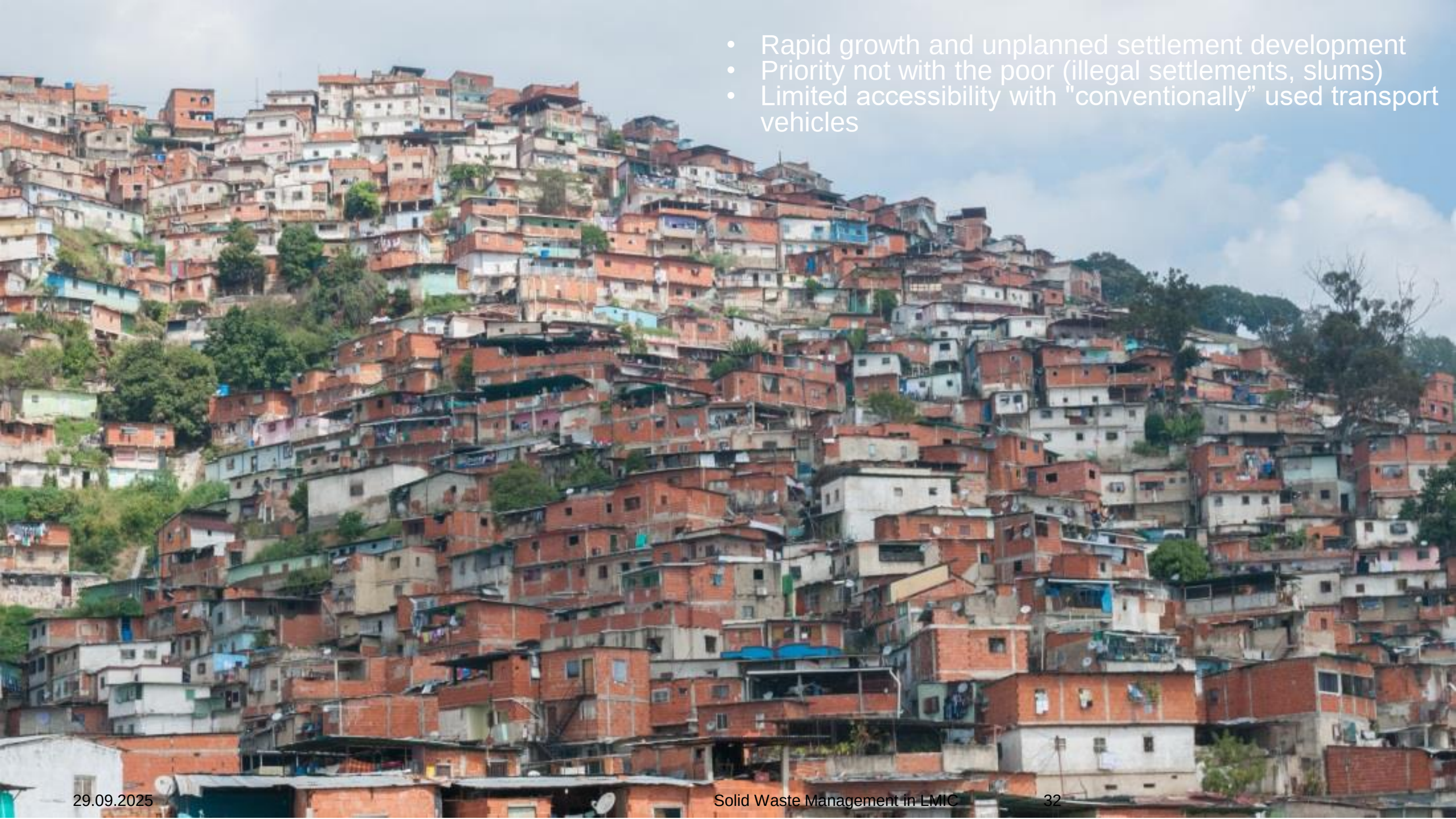
Secodnary collection



Collection and Transport

Primary 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 !**



- Rapid growth and unplanned settlement development
- Priority not with the poor (illegal settlements, slums)
- Limited accessibility with "conventionally" used transport vehicles

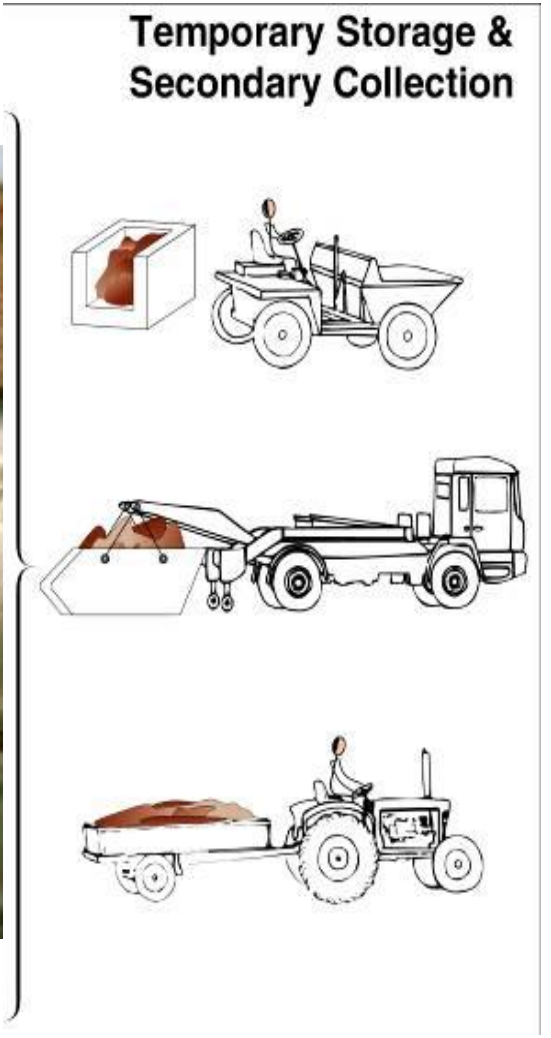
Collection and Transport

Transfer points

Transfer refers to the movement of waste or materials from the primary collection vehicle to a secondary, generally larger and more efficient, transport vehicle.

Compactor truck, Vietnam

Transfer point, Indonesia

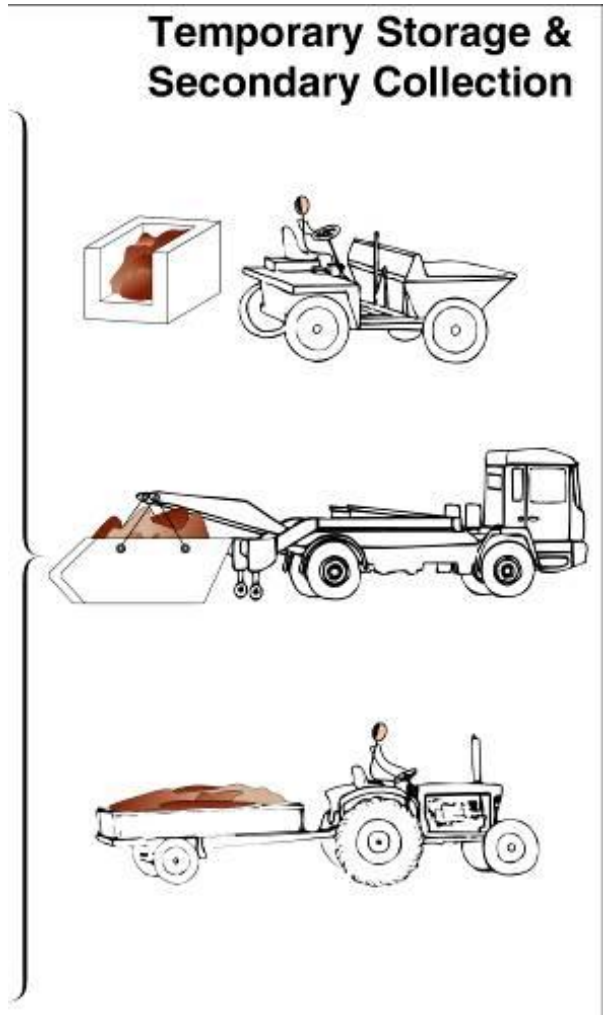


Collection and Transport

Transfer points

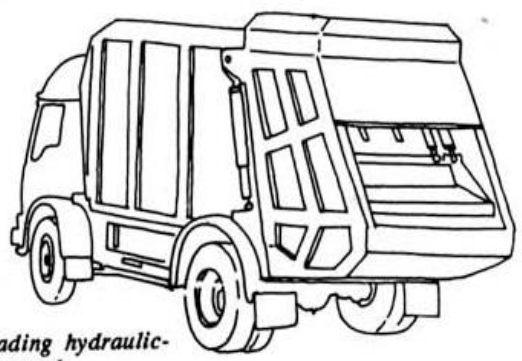
What is wrong here?

“Technology” includes operation and management !!

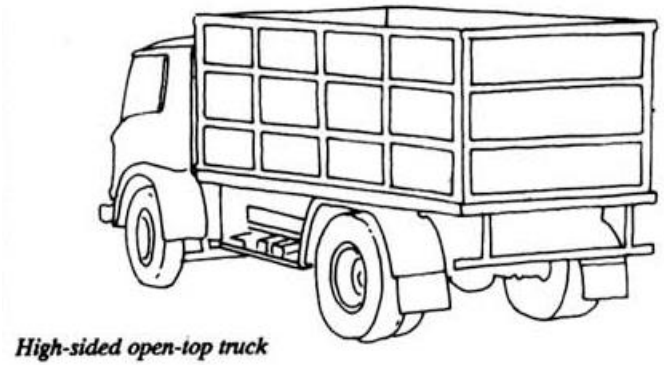


Collection and Transport

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 hydr
compactor 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 neighbourhood: burned or dumped

Compactor truck

- Wider paved streets
- Easy and quick pick up (in bags or containers)
- **Low density** and low moisture content

e:

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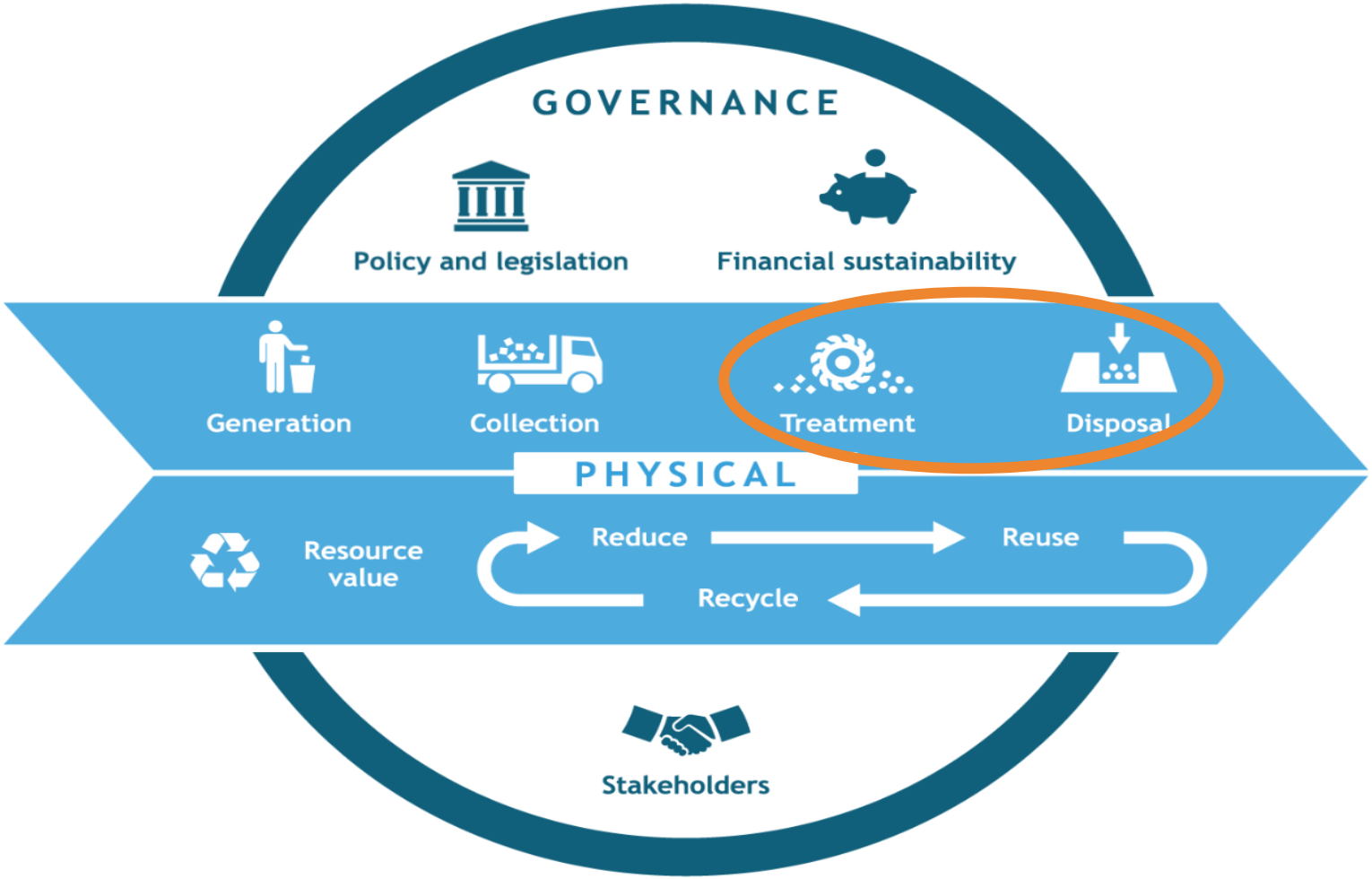
ISWM Framework



Source: MSWM-MOOC Sandec (2016)

Treatment – Mixed waste

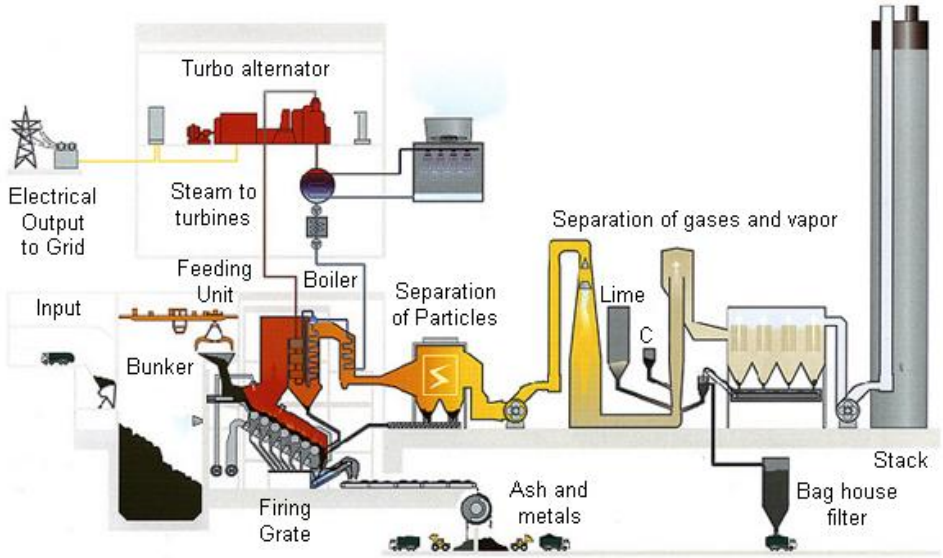
Energy valorization through incineration

- 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
b = Textiles
c = Wood & Leaves
d = Food waste
e = Plastic & Rubber
W = Water



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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

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

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

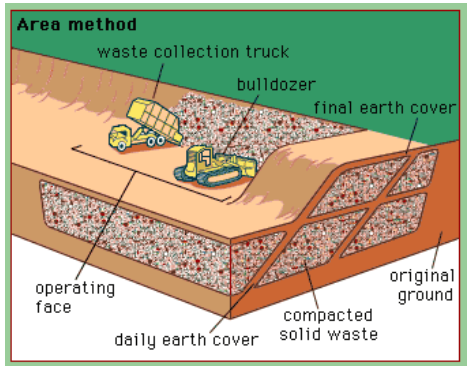
- Common practice with hazardous wastes (e.g. hospitals)
- Ovens. Often uncontrolled burning conditions.

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)

Fulfilling these requirements is expensive…



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

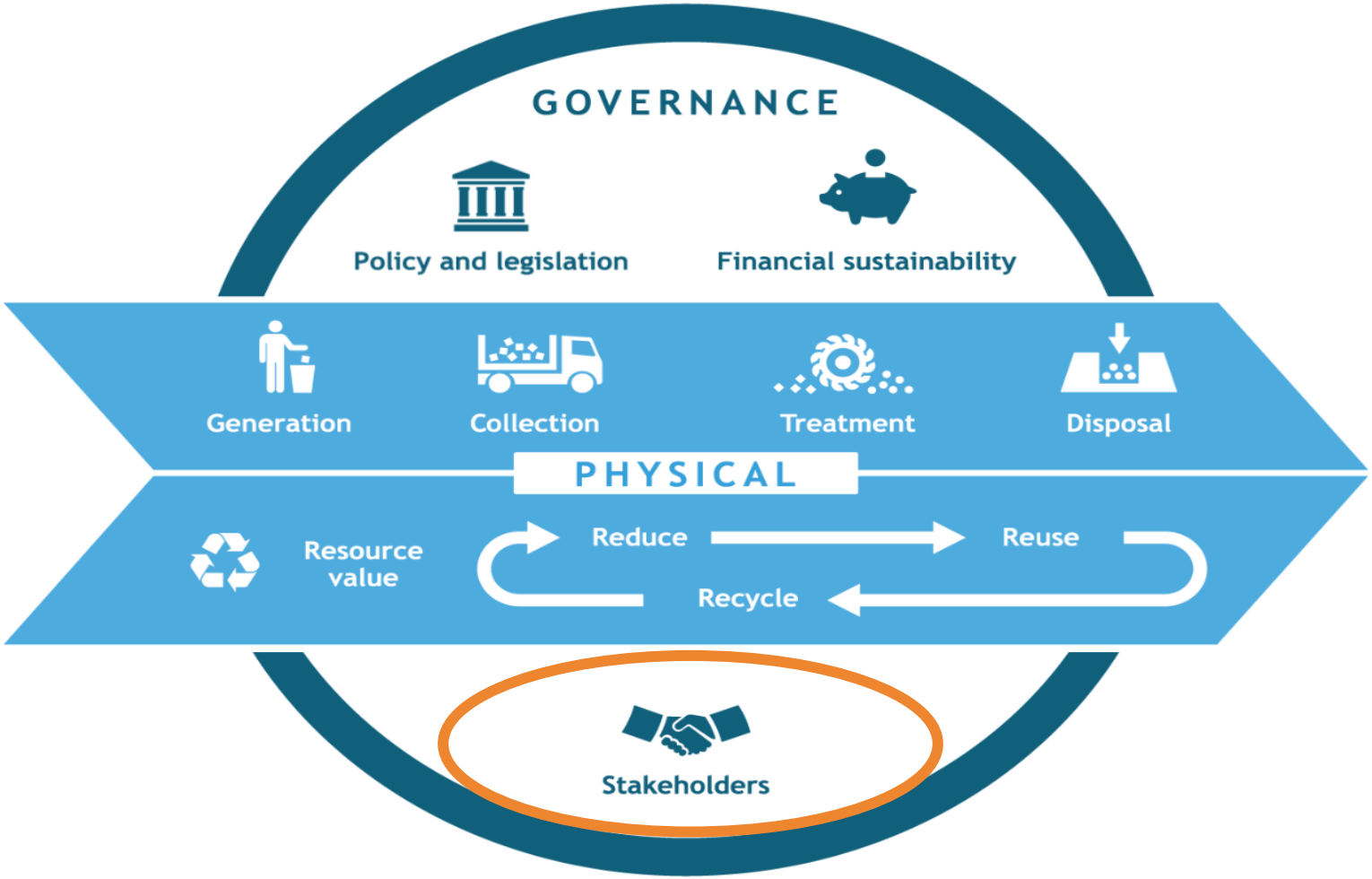
Disposal

Video – SWM disposal

What bad practices can you see in this video?

eawag
aquatic research

ISWM Framework



Source: MSWM-MOOC Sandec (2016)

Stakeholders

SWM can not be solved with innovative technology or engineering alone.

Who are the stakeholders?

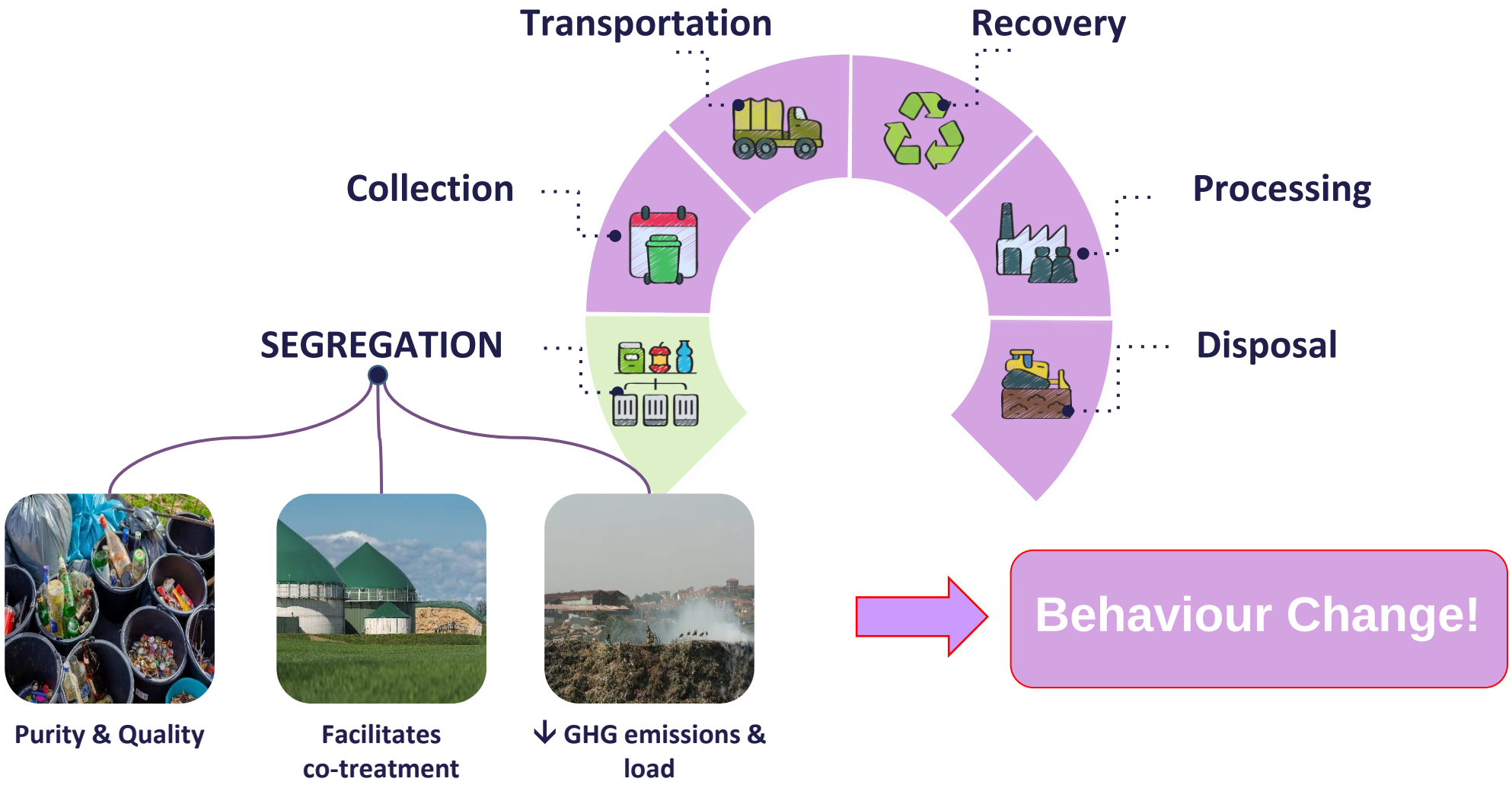
- Waste generators
- Central/provincial government
- Municipality
- NGOs & CBOs
- Private formal sector
- Private informal sector
- Internal & external support agencies

Household Waste Segregation

Policy and Legislation
e.g. “avoiding plastic”

Stakeholders

Importance of segregation



Stakeholders

How do we achieve behaviour change?

Intervention: Providing Infrastructure

Targeted Behaviour: Segregation

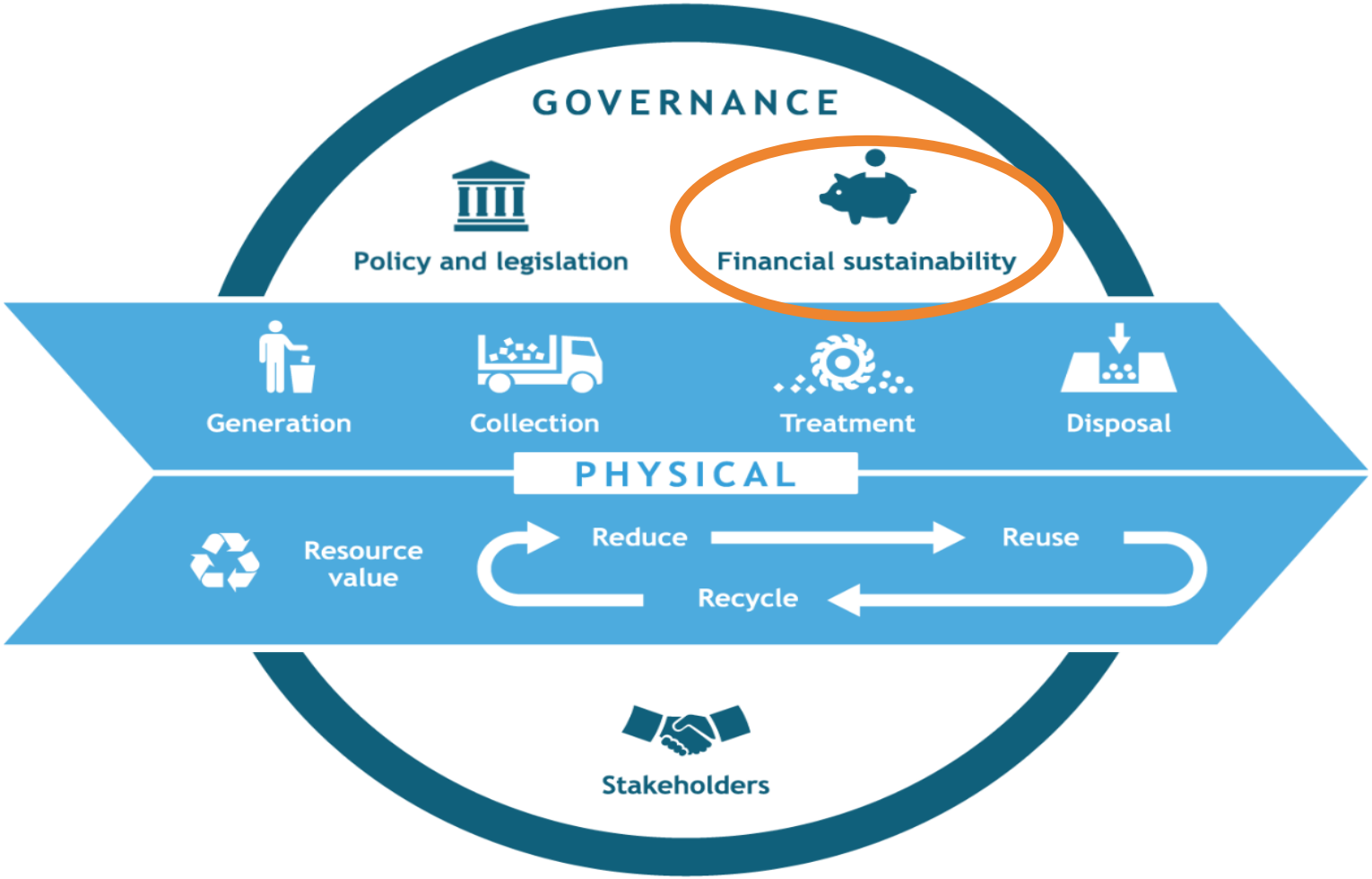
RANAS

- **R**ISK
- **A**TTITUDE
- **N**ORMS
- **A**BILITY
- **S**ELF-REGULATION

Approach to systematic behaviour change

https://ranas.ch/

ISWM Framework



Source: MSWM-MOOC Sandec (2016)

Financing sustainability

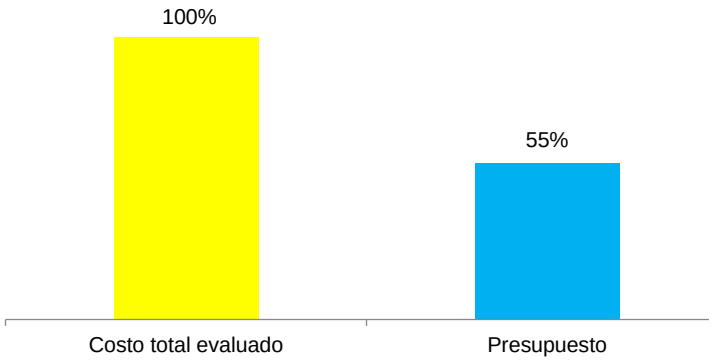
Costs for a good service

- Investment costs
- O & M costs
- Externalities

Rarely known

- Multiple actors
- No separate budget
- Money used elsewhere

Example: Villa Montes - Bolivia



Financing sustainability

Costs for a good service

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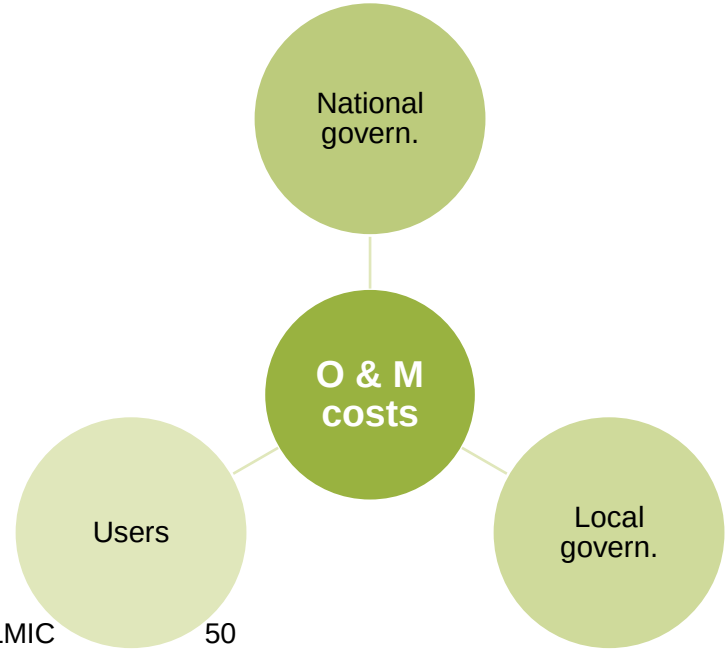
Most common revenue sources:



Typical costs

Table 5.2 Typical Waste Management Costs by Disposal Type

US$/tonne

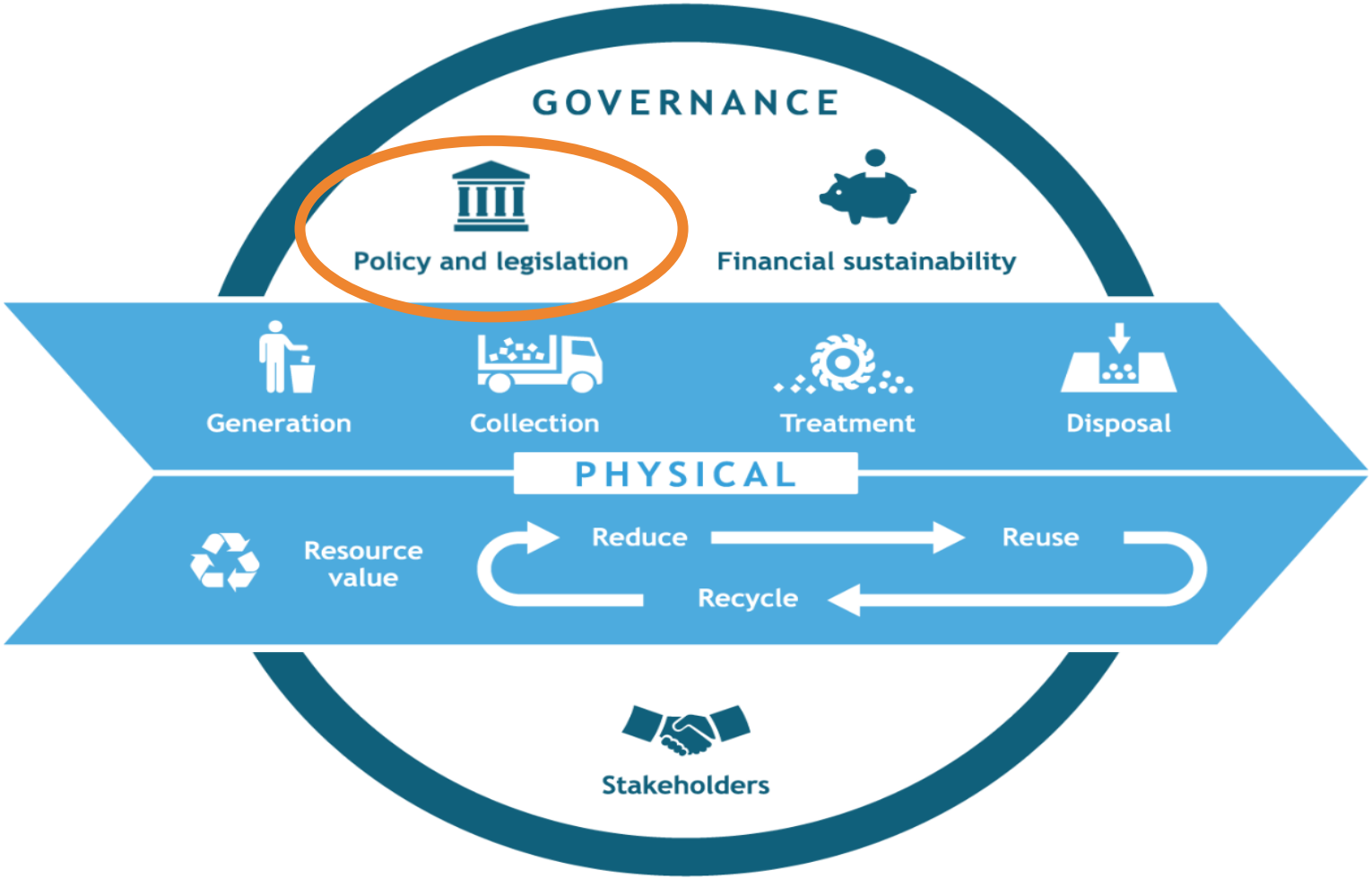
	Low-income countries	Lower-middle-income countries	Upper-middle-income countries	High-income countries
Collection and transfer	20–50	30–75	50–100	90–200
Controlled landfill to sanitary landfill	10–20	15–40	20–65	40–100
Open dumping	2–8	3–10	—	—
Recycling	0–25	5–30	5–50	30–80
Composting	5–30	10–40	20–75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

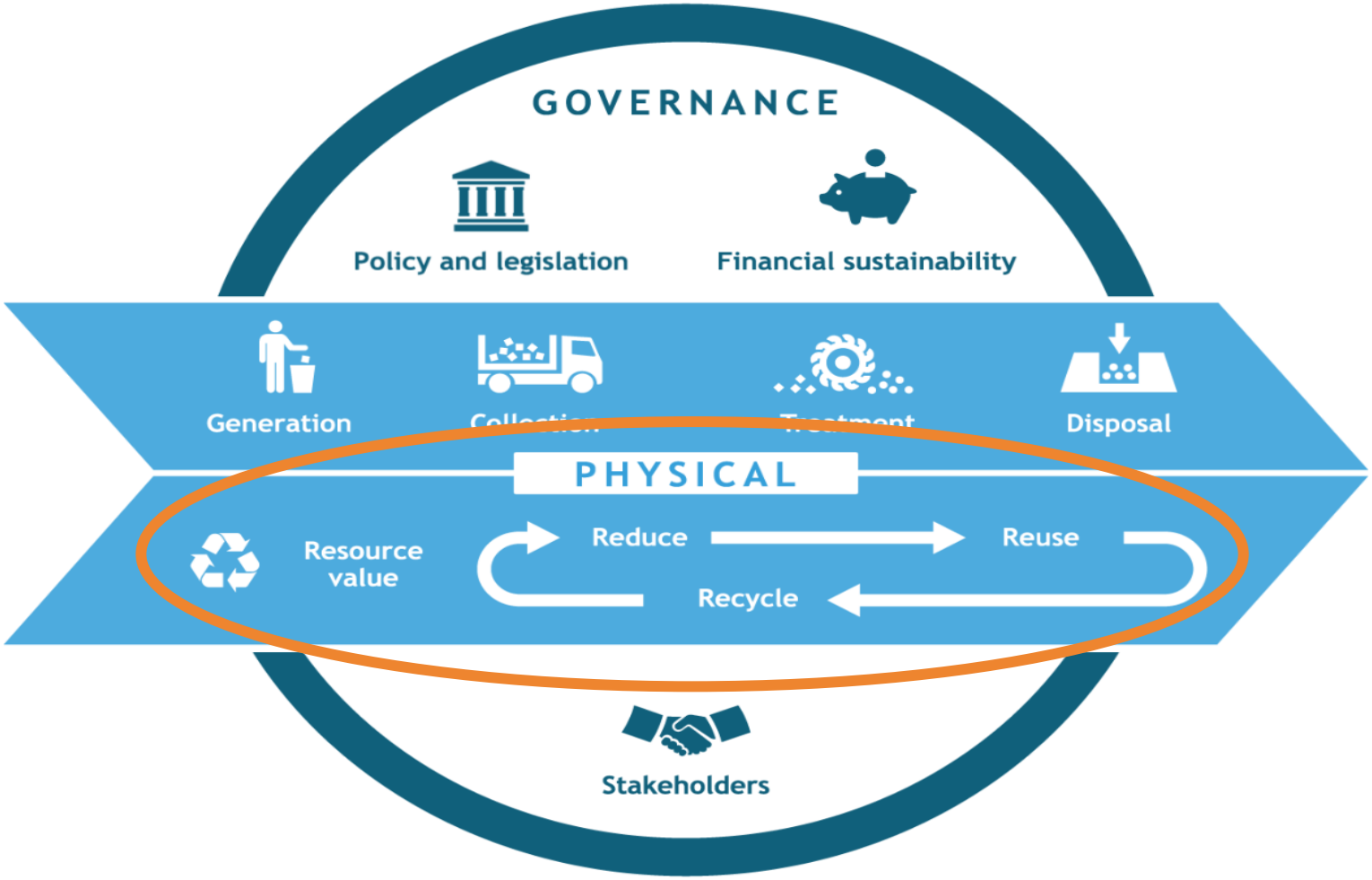
Policy and legislation: Waste hierarchy

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

Policy and legislation: Interesting case of plastic ban

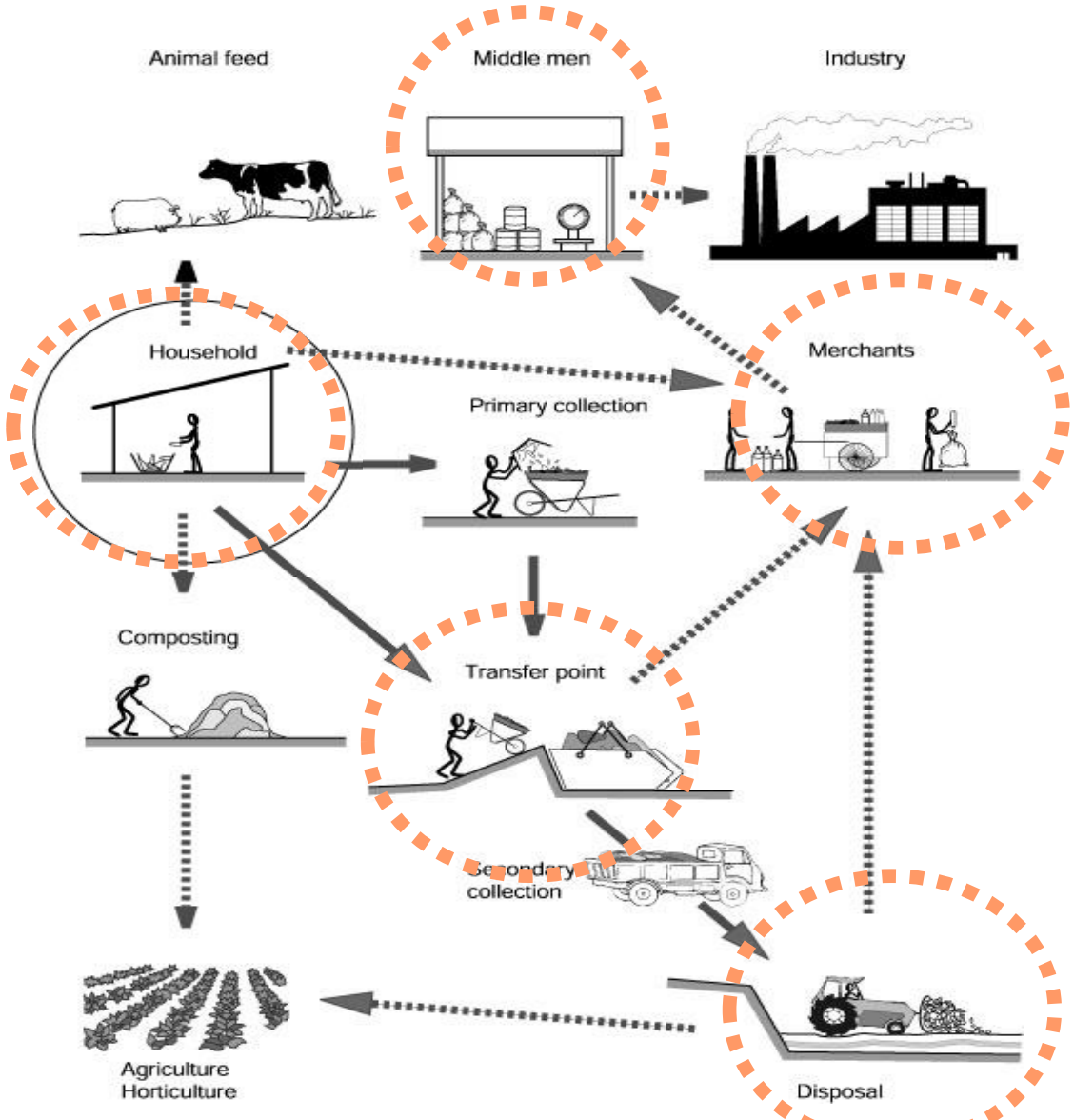
→Is it replaced by another material? Is it actually better?
→For example biodegradable plastics, or paper?
→Condiser LCA & waste management capacities to take informed decisions

ISWM Framework



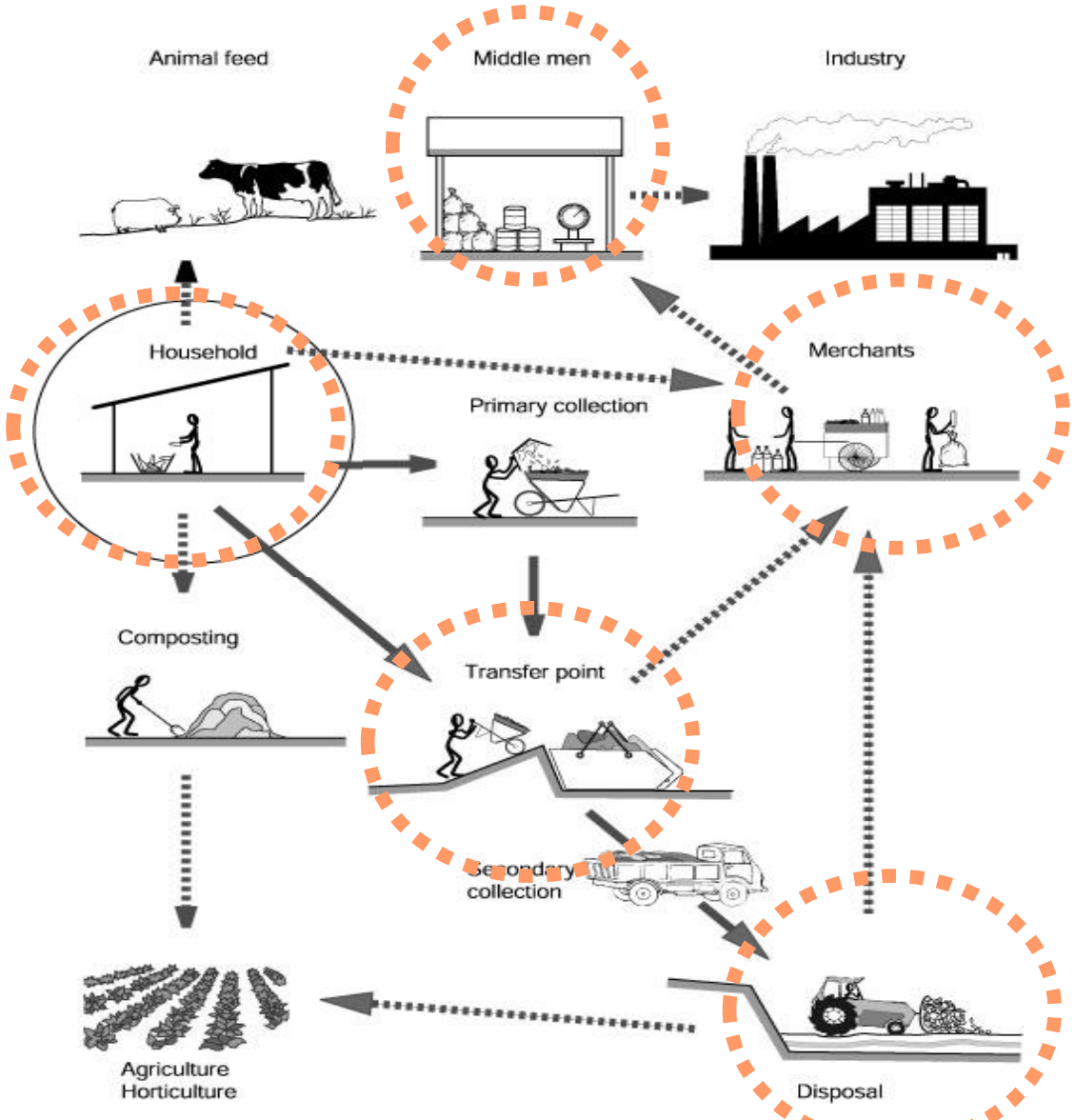
Source: MSWM-MOOC Sandec (2016)

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

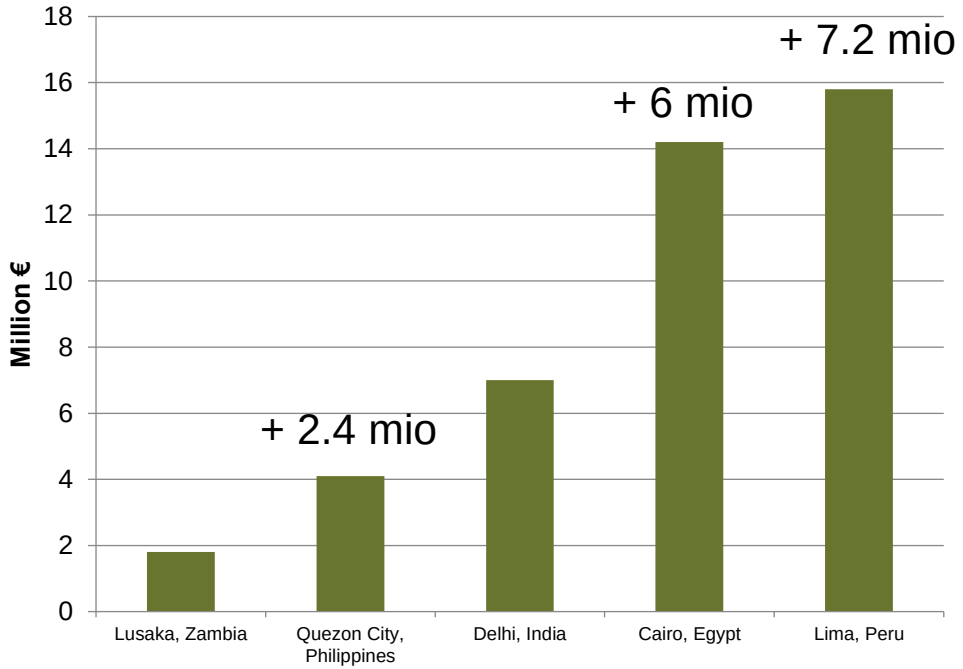
Recycling system – Informal sector

- 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

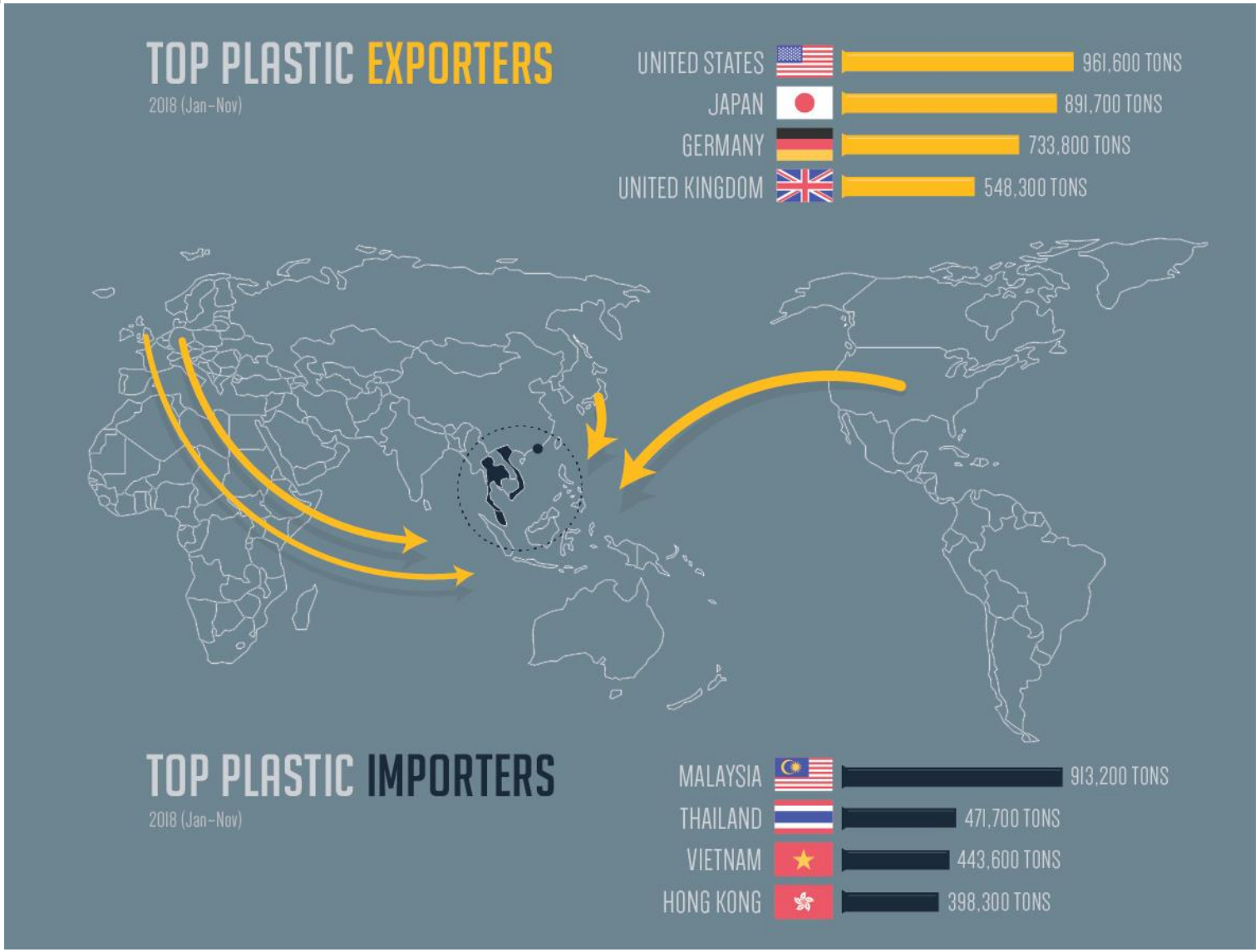
https://www.youtube.com/watch?v=bxF3-wdxUKk&list=PLNG_YQG6XtkWVi2lu6cMtnZ86Q6v8RM7A&index=6

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

Recycling system – Export Worldwide

Plastic export worldwide

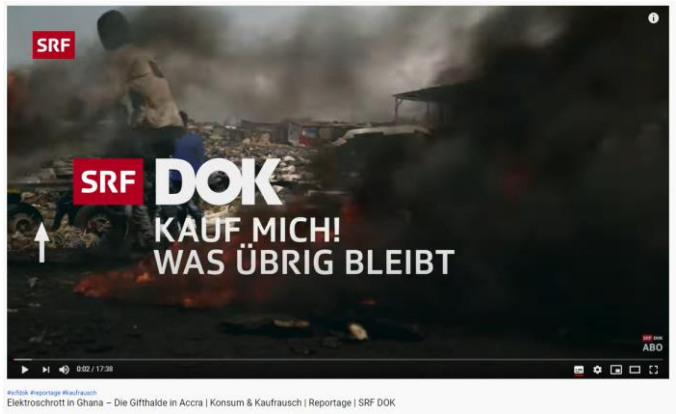
- Wide range of plastic types!
- Not all easily recyclable
- Global/transboundary issue



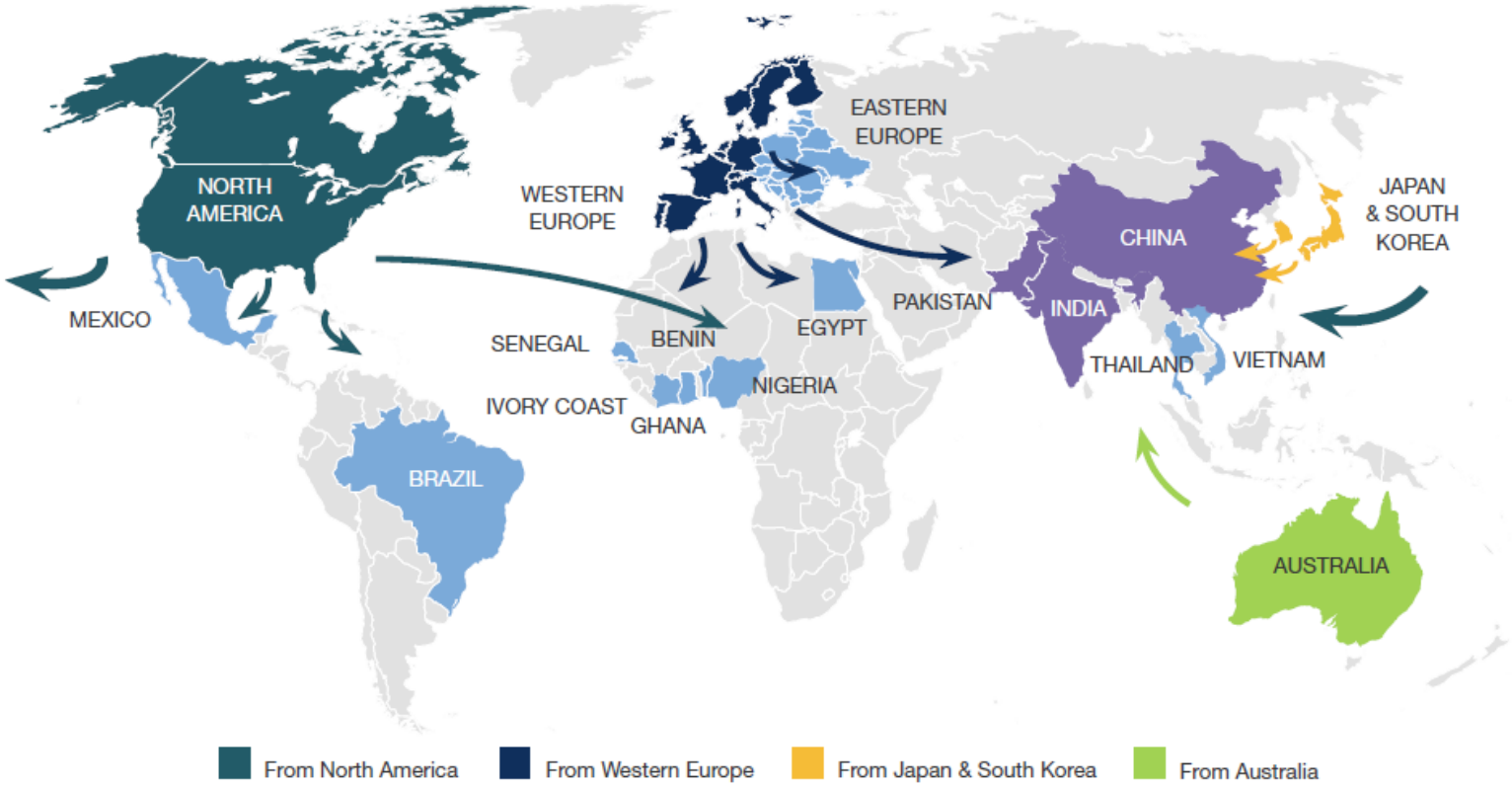
Recycling system – Export Worldwide

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



Generation

Waste Fractions

Recyclables

PLASTIC

CARDBOARD & PAPER

METAL

GLASS

OTHER

Organics

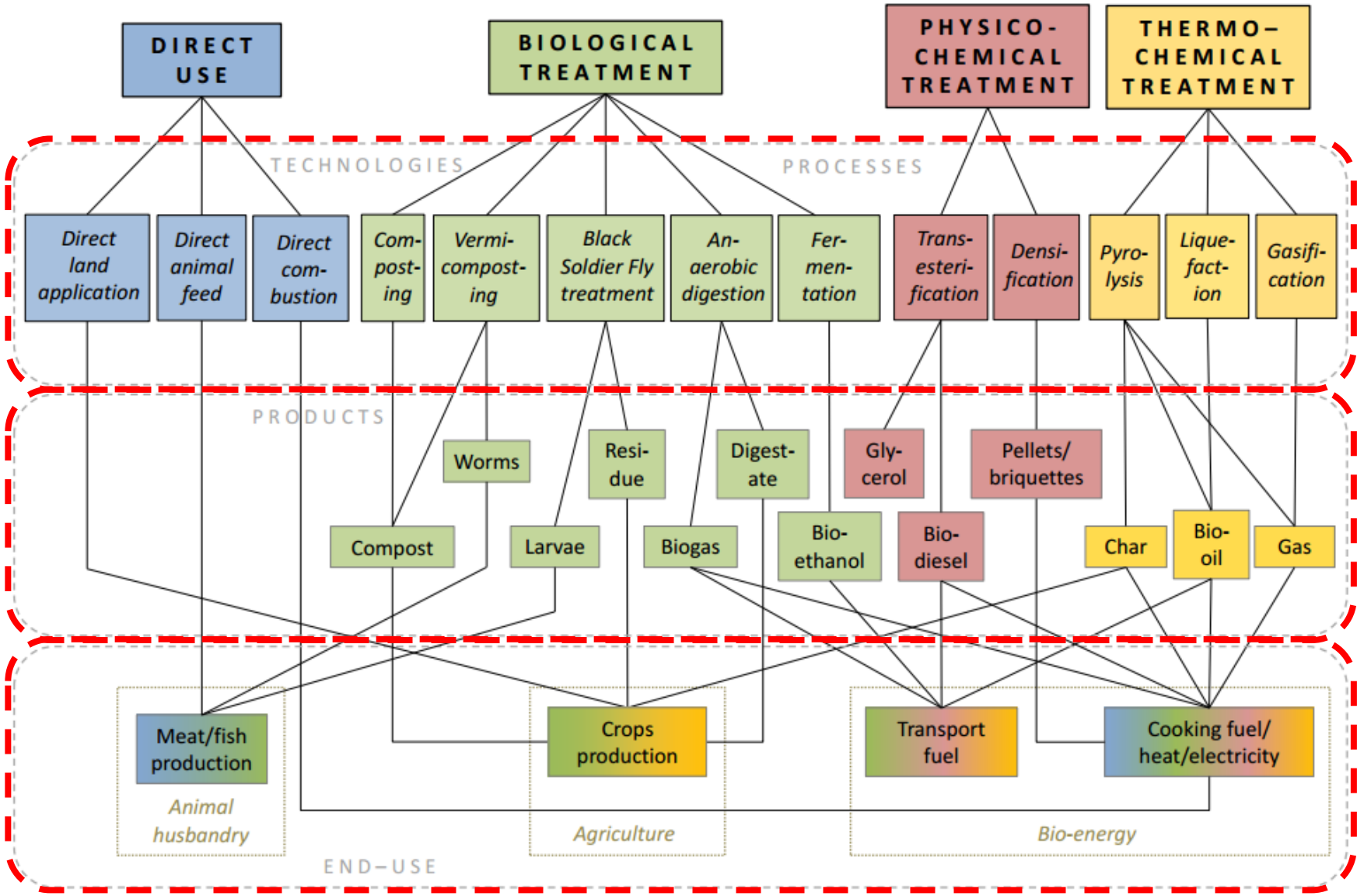
Residual

Organic Waste Treatments

What problems can organic waste cause?

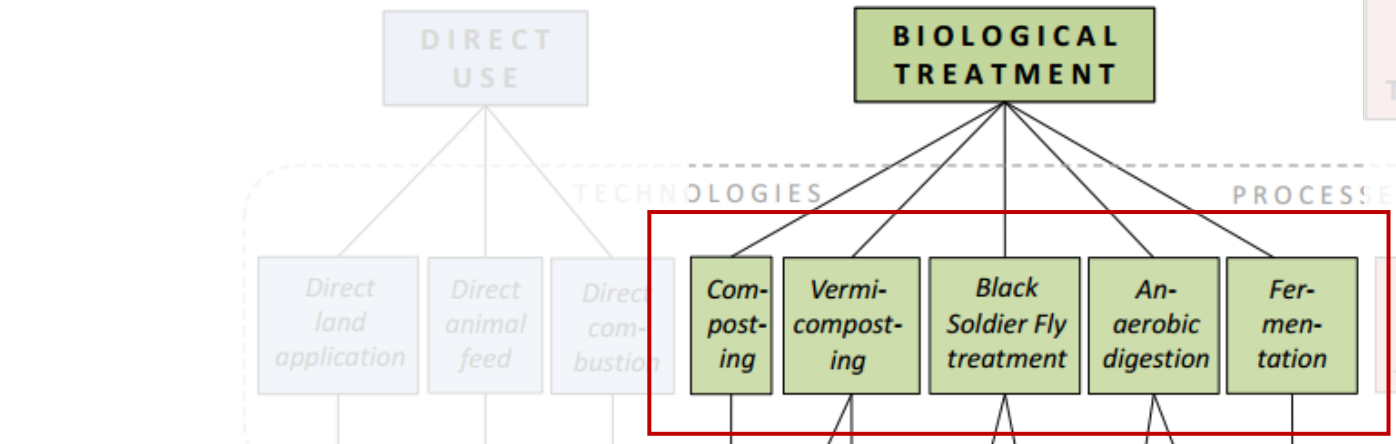
- **Health threats**
  - Hygiene
  - Pest attraction
- **Environmental threats:**
  - Methane emissions
  - Ground water pollution
- **High moisture**
  - High density which affects collection and treatment options.
  - Corrosion of equipment
  - Not suitable for incineration (low heating value)
  - 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



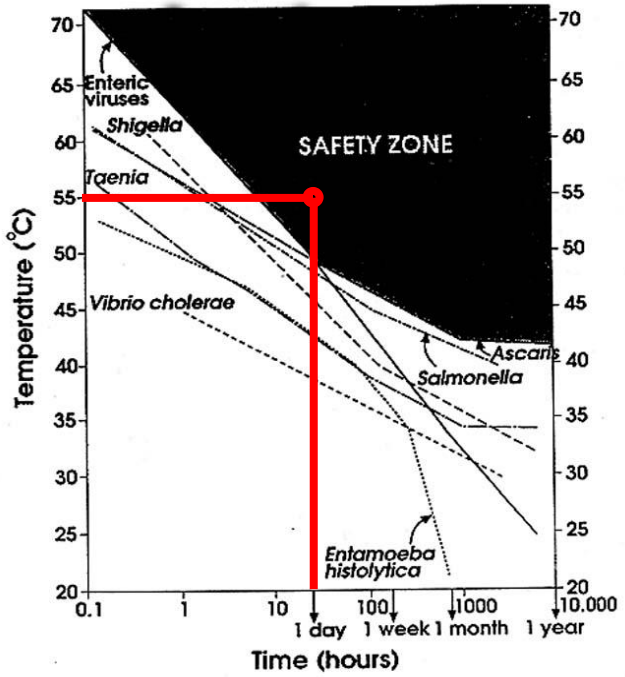
Composting

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



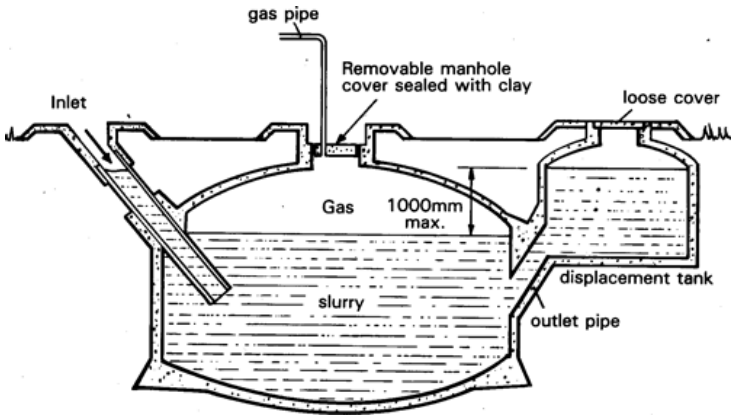
Some treatment data	
Moisture	40-60%
C/N of waste	20-50 (opt. ~25)
Water needs	10-70 L/ton
Waste reduction (dry basis)	25-50%


Windrow composting in Bolivia


Bin composting in Bangladesh

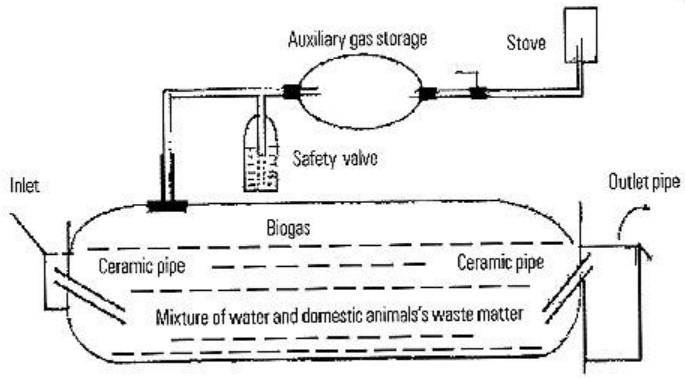
Anaerobic Digestion/Biogas

- 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*



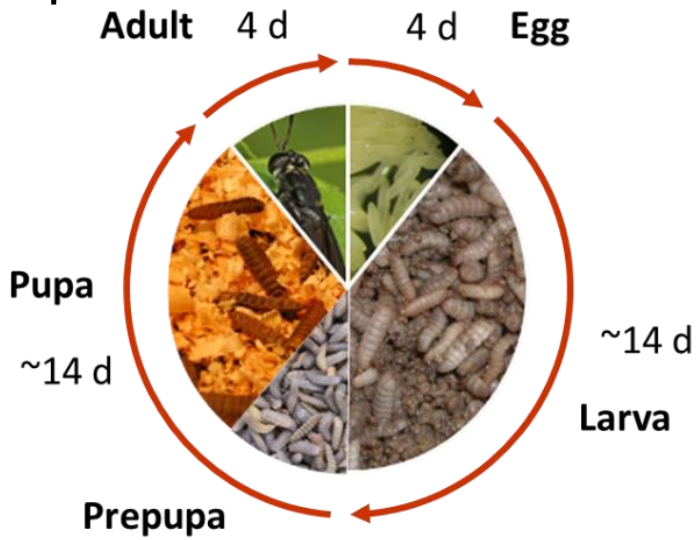
Some treatment data	
Moisture	60-95%*
C/N of waste	16-25
Water needs	0 - 5,000* L/ton
Waste reduction (dry basis)	0 - 25%*

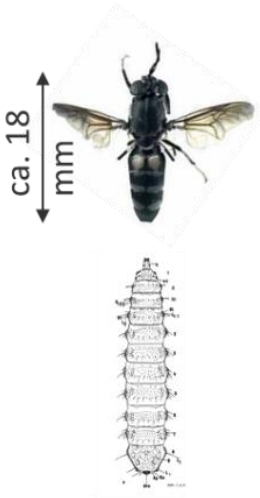
*Depends on system



Black Soldier Fly, *Hermetia illucens*

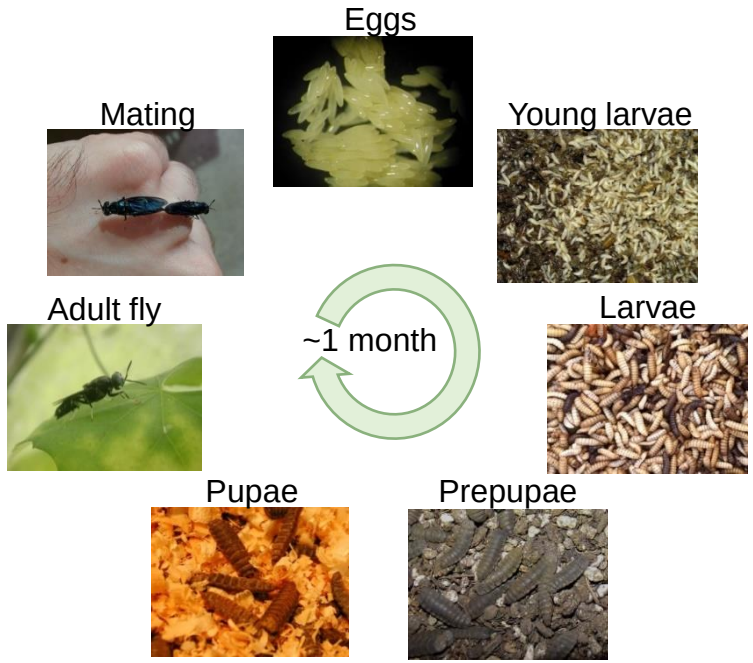
- Organic waste is eaten by growing larvae under **aerobic conditions**.
- Larvae develop and are harvested before pupation
- Products:
  - Larvae, contain 40% crude protein and 30% of fat, can be processed and **replace fishmeal** in animal feed
  - Residue, contains valuable nutrients and can be used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

Black Soldier Fly

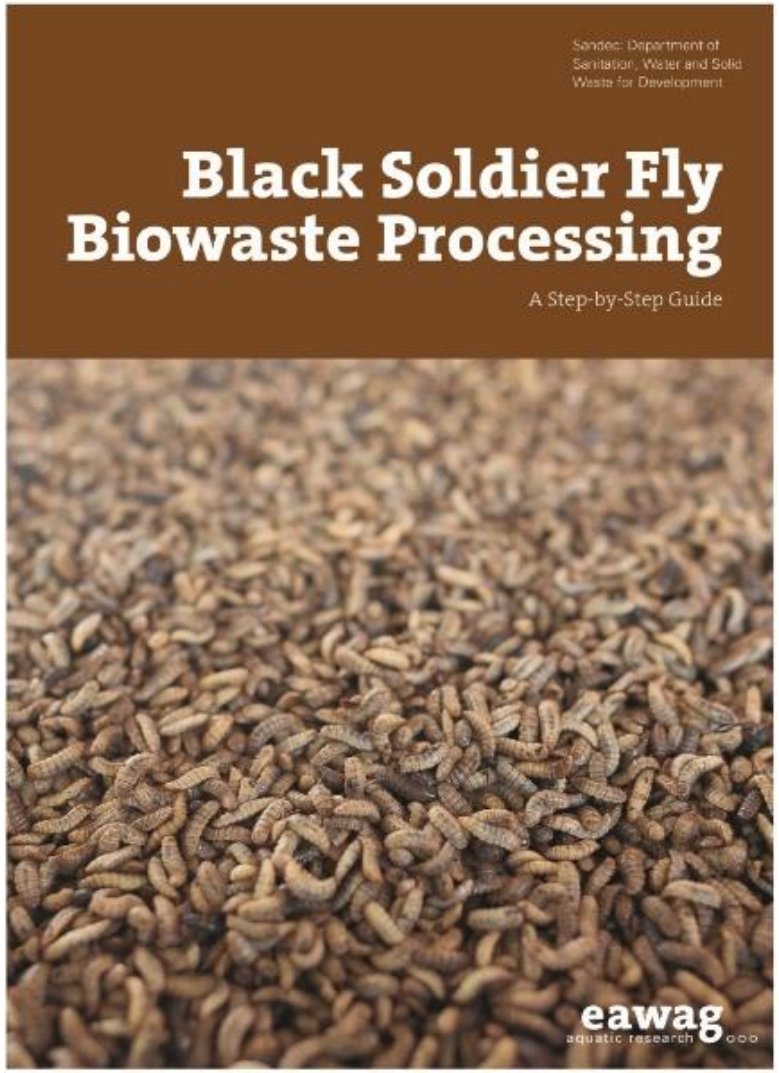


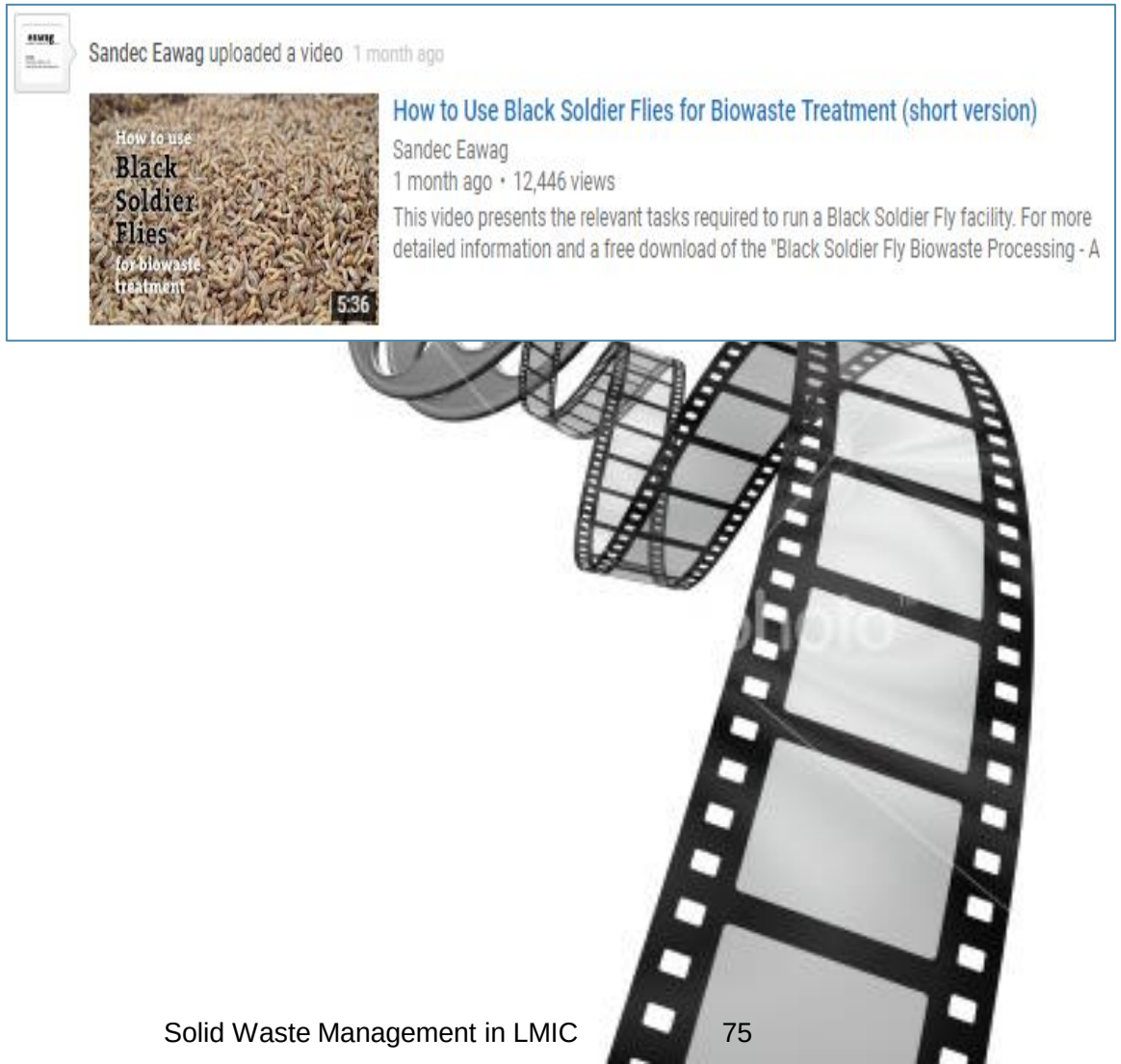
- Larvae feed on **organic material**
  - Fruits & vegetables
  - Food waste
  - Slaughterhouse waste
  - Animal manure
  - Human faeces
- Conversion of **1 ton** of food waste into **250 kg** fresh larvae within **14 days**
- Larvae contain **~40% protein** and **~30% fat**
- Material reduction of **70-85%** dry matter
- The adults flies don’t eat. Minimizes risk of disease transmission

Creates value from waste

Good substitute
- **Fishmeal**
- **Soymeal**

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?

Important crit

- Waste type t
- Market dema nd-product
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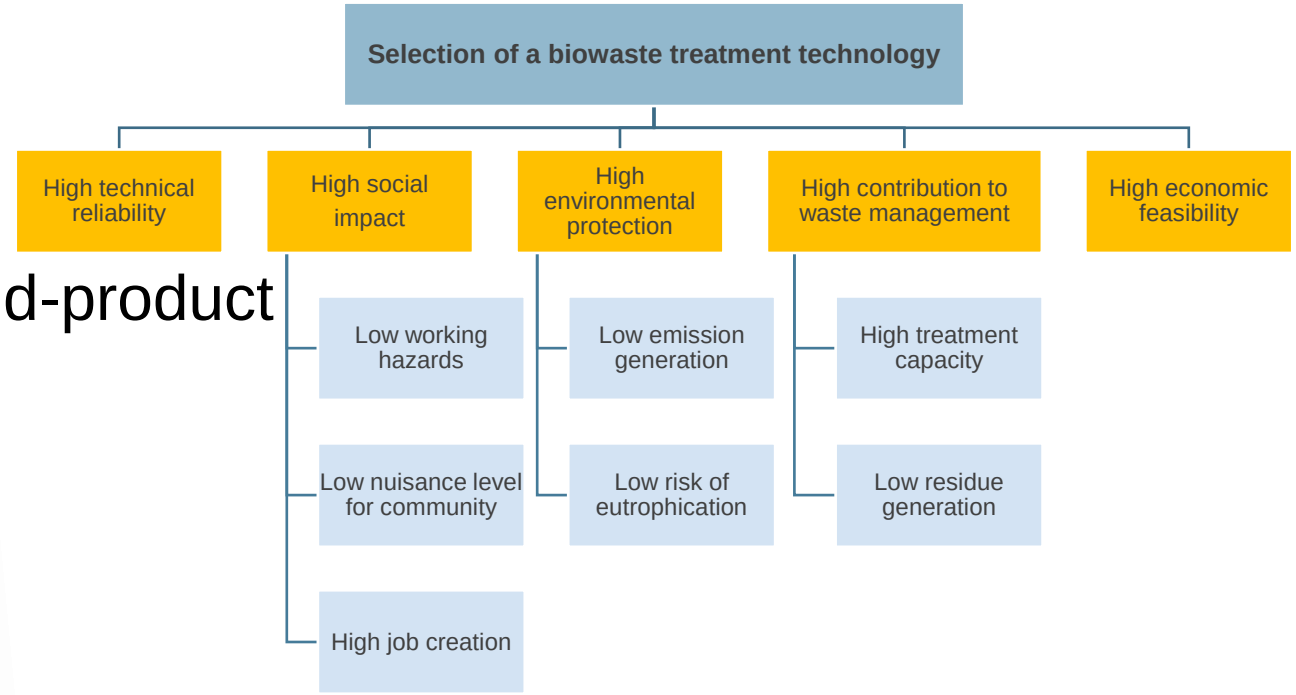

Take Home Messages

- 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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