Risk of antimicrobial resistance spreading via food loss and waste

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Outline

Narrative review (about 150 references)

- Food loss and waste- *definition and numbers*

- AMR in Food loss and waste?
- Food waste management processes and AMR
    - Feed and pet food
    - Aerobic fermentation
    - Anaerobic digestion
    - Landfill

- Gaps and limitations
- Conclusion- Discussion

FLW and AMR- Expert's consultation


Food and Agriculture Organization of the United Nations

FAO Joint Centre for Zoonotic Diseases and Antimicrobial Resistance (CJWZ) report

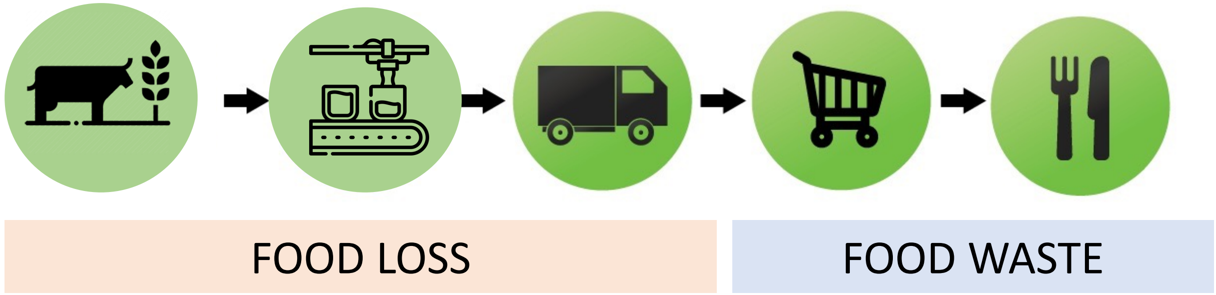
Expert consultative meeting on a One Health approach to reducing food loss and waste in relation to animal diseases and antimicrobial resistance

Virtual meeting
13 October 2022

https://www.fao.org/3/cc7732en/cc7732en.pdf

Food Loss and Waste

- Each year, about **1/3 of all food produced for human consumption is lost or wasted (1.3 billion tons)**
- FLW is the decrease in quantity or quality of food along the food supply chain
- **FLW results from poorly functioning agrifood systems**

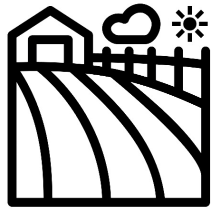


https://www.wfpusa.org/

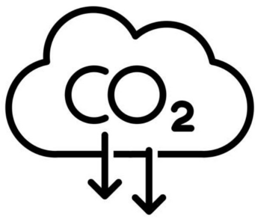
- **FLW has implications for food security, economy and environment**

828 million undernourished *people*
3.1 billion *without access to healthy diets*

Water footprint of ***250km3***
(3x Genova lake)

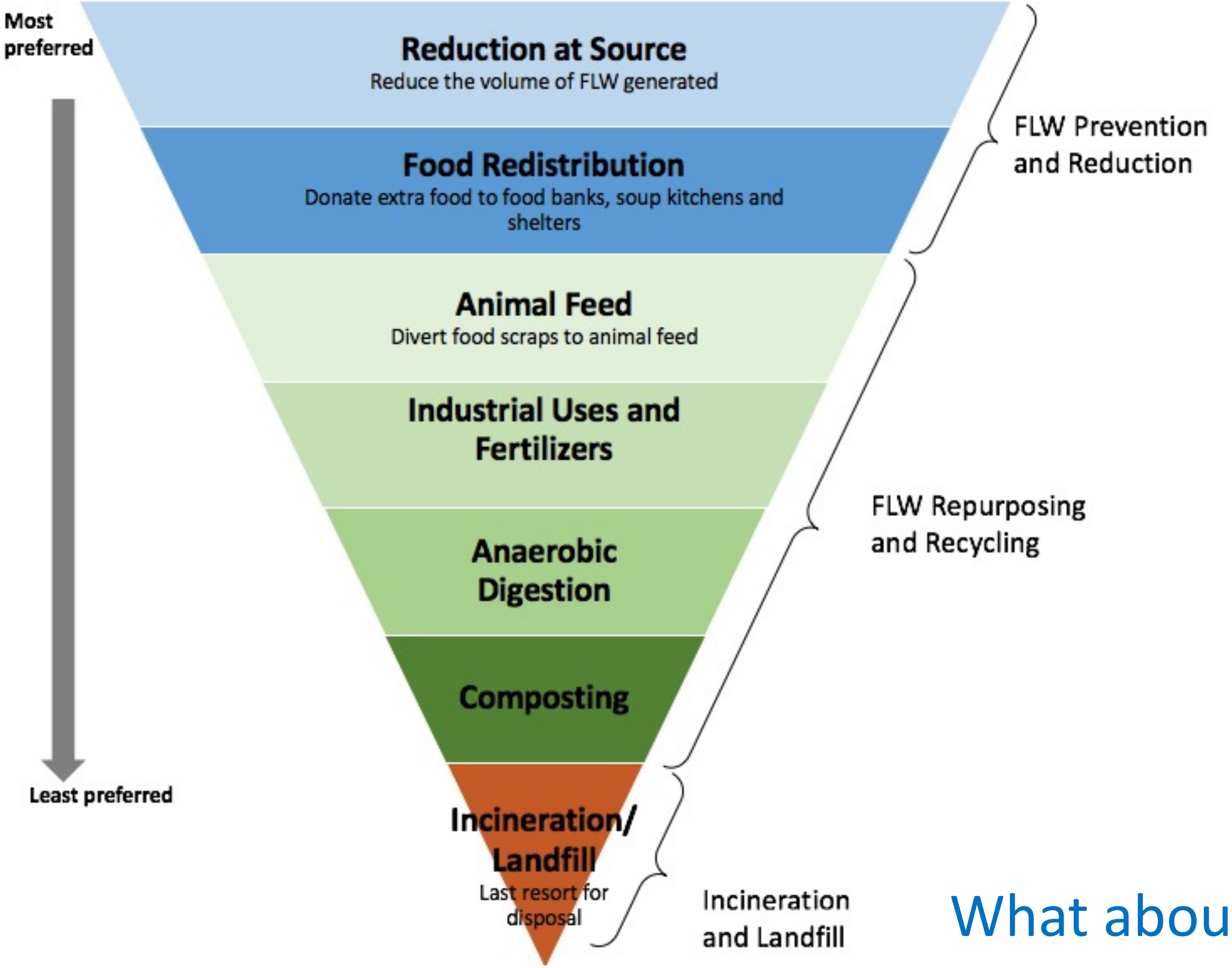


28 % of the world's agricultural area *used to produce food that is lost or wasted*



8 to 10% of global greenhouse gas *emissions*

A hierarchical approach for food loss and waste



12 RESPONSIBLE CONSUMPTION AND PRODUCTION

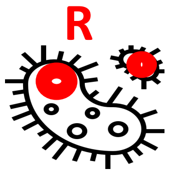
Target 12.3
By 2030, halve per capita global food waste and reduce food loss

FAO Voluntary Code of Conduct (CoC) to reduce FLW

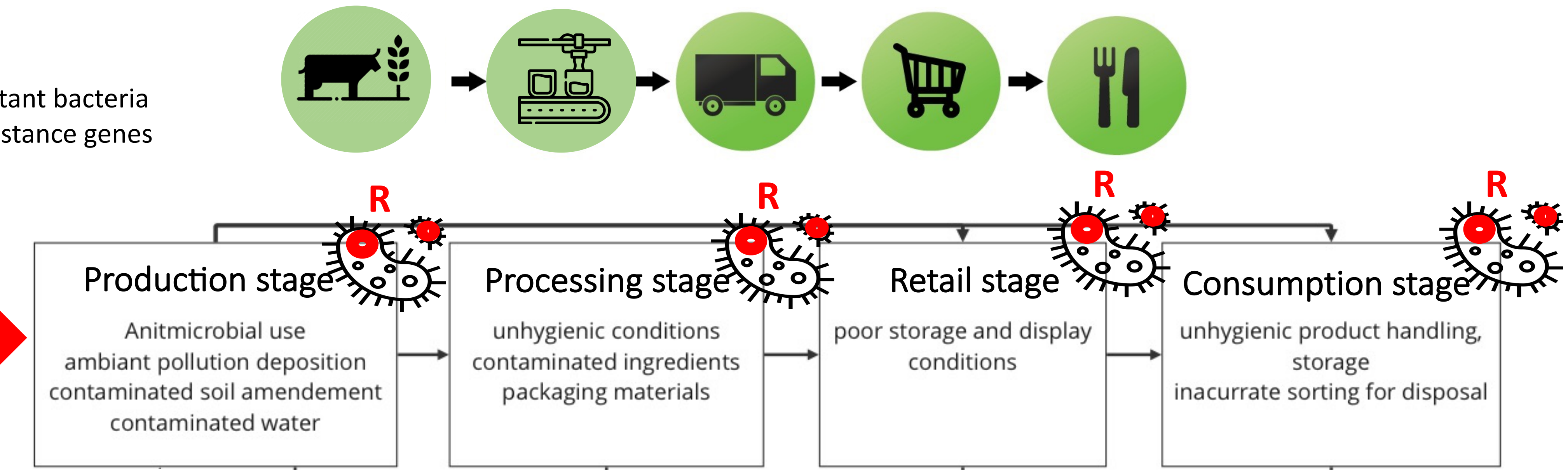
Article 4.8 encourages governments to structure and implement public policy frameworks to ensure safety and quality of reused and/or recycled by-products and inedible parts of the food supply chain. If that surplus cannot be reused or redirected, waste disposal procedure should also be explicit.

What about antimicrobial resistance in FLW?

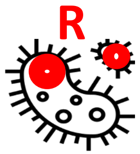
AMR in the food chain and in food waste?



ARB= antimicrobial resistant bacteria
ARGs= antimicrobial resistance genes



AMR in Food waste

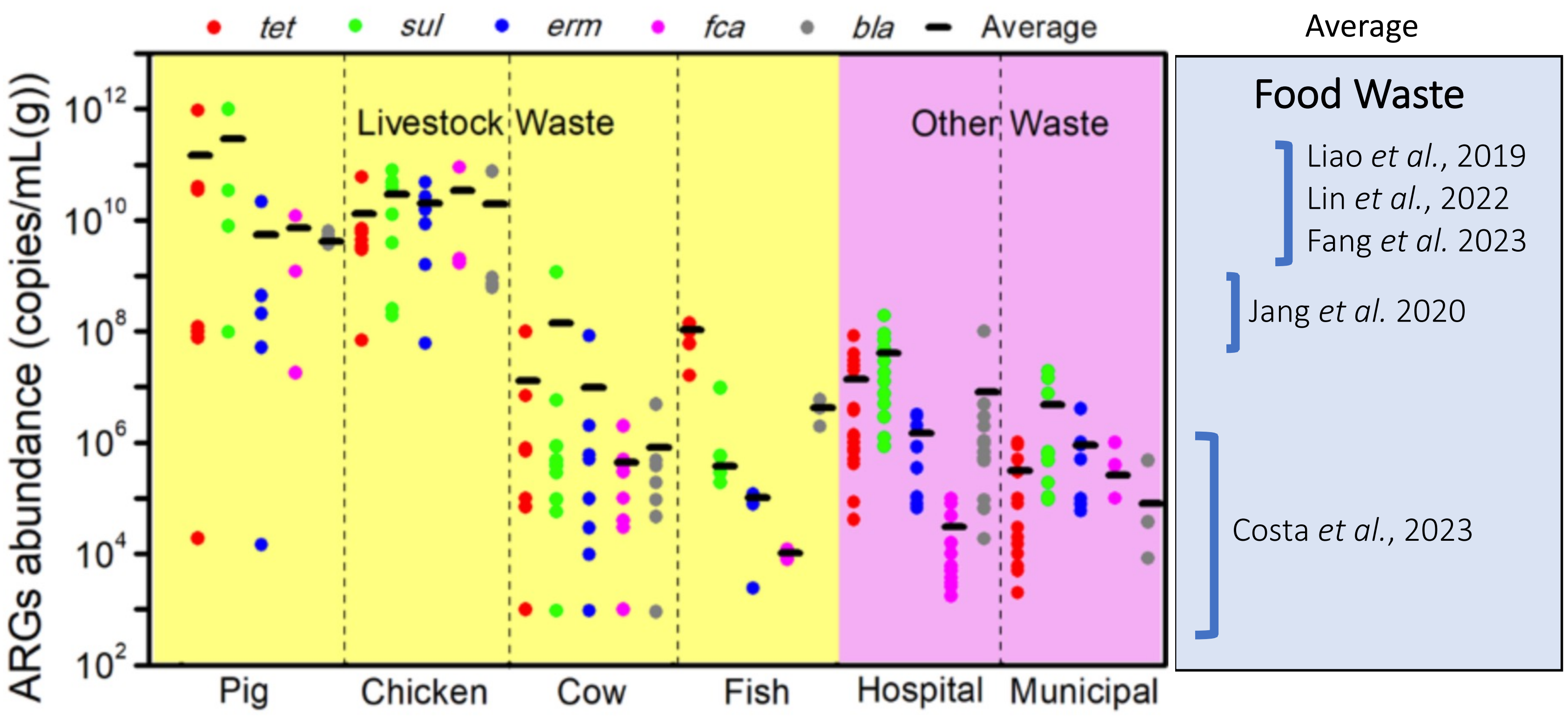


- **FW is an excellent substrate for bacterial growth.**

Examples:

- **Antimicrobial resistant bacteria**: food wastes from meat slaughterhouses, dairy and restaurants. More than 50% of all the strains were resistant to Vancomycin, Neomycin and Methicilin, which belong to third-generation antibiotics (Yashwant 2022). 11% of isolates from dairy waste and 8% from meat waste were resistant to about 7 out of 9 antibiotics (Periasamy *et al.*, 2023)
- **ARGs:** In the US, a study showed that food waste collected from school, hospitals, restaurants or households contained ARGs. **The *tet(M)* and *blaTEM* were present in 96% and 97% of samples respectively** (Thakali *et al.*, 2022).
- Few studies with **ARGs abundances ranging from about 10^3 copies/g to 10^{11} copies/g** before treatment (Costa *et al.*, 2023) (Liao *et al.*, 2019) (Lin *et al.*, 2022) (Fang et al. 2023)
- Food wastewater effluent ARGs ranged from **1.4×10^8 to 5.1×10^9 copies/mL** (Jang *et al.*, 2020)
- ARGs found **not only in FLW of products from animal origin**

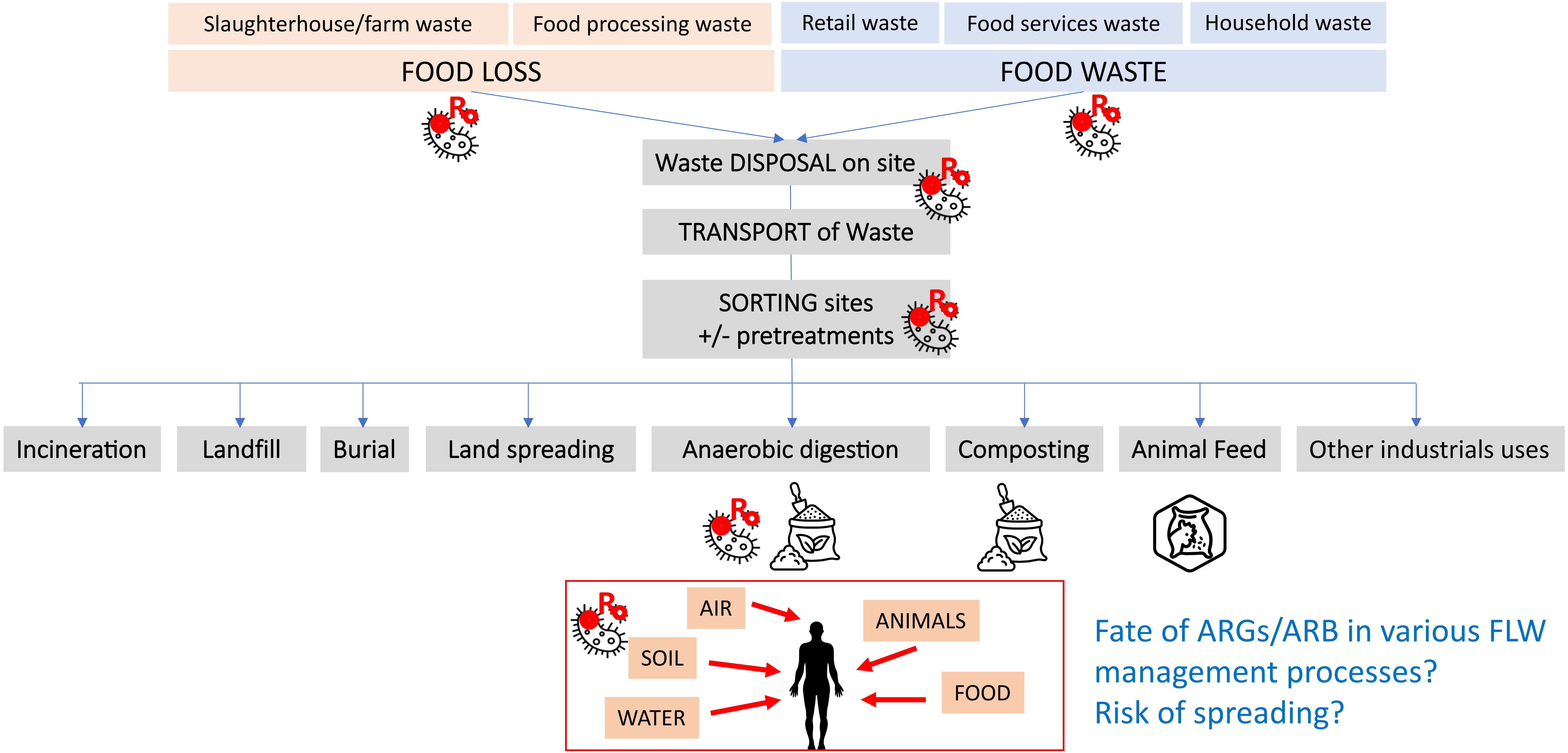
Compare to other types of waste



From He et al. 2020

Food loss and waste is a neglected source of AMR

Food waste management processes



Fate of ARGs/ARB in various FLW management processes?

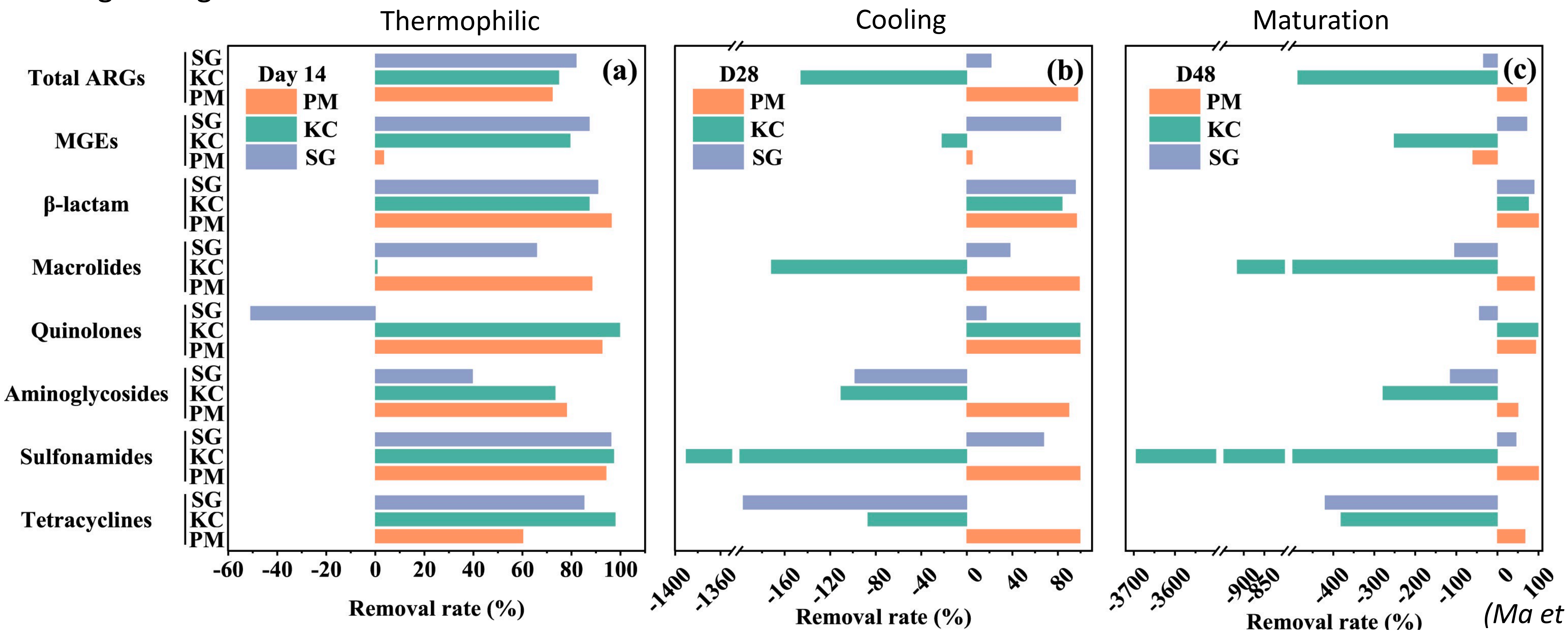
Risk of spreading?

Comparison with other AMR contaminated wastes

PM: Pig manure
KC: Kitchen Waste
SG: Sewage Sludge

Initial ARGs levels PM>SG>KC

Composting , ARGs Removal rate over time



(Ma et al. 2023)

ARGs enrichment in kitchen waste composting

Not possible to extrapolate data from other organic wastes to FLW

Aerobic fermentation- Composting

Organic wastes

Composting process

Organic fertilizer

In UK- Municipal food compost 10 samples
One showed complete resistance to all 6 antibiotics tested (lincomycin,tobramycin, minocycline,amoxycillin, ciprofloxacin, florfenicol).
No compost displayed complete antibiotic sensitivity. All have more than 2 resistances (Furukawa et al. 2018)

Data showed that compost samples are contaminating with ARGS and ARB.

Aerobic fermentation- Composting

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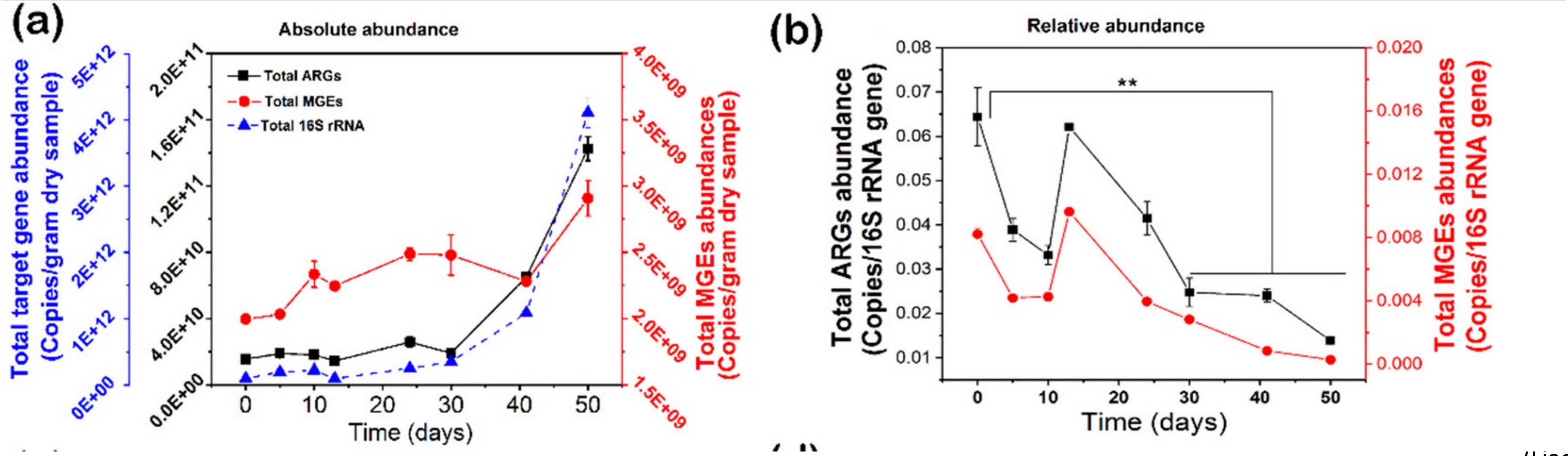
Organic wastes

Composting process

Organic fertilizer



(Liao et al. 2019)

Conventional composting might not be sufficient to reduce AMR risk

Aerobic fermentation- Composting

Pre-treatments
Biodrying + mature compost ↓
Initial high temperature (60°c)↓

Co-composting
optimize moisture and C/N ratio
Various results
↑↓

Microbial inoculants
↑

Composting parameters
- Temperature ↓
- Ventilation ↓
- Residence time
- Material stacking

Additives
- Biochar
- Nano zerovalent iron
- Zeolite

No data on food waste

↓ Decrease ARGs
↑ increase ARGs

Aerobic fermentation- Composting

Composting parameters

	Material movement	Material stacking	Ventilation	time (days)	T°C
SAC	static	vessel	pressure+ ventilation	45	+++
ASPC	static	pile	Pressure+ ventilation	50	++
DPC	dynamic	pile	Natural ventilation	30	+
MC	dynamic	vessel	Pressure+ ventilation	15	+

Degradation rate of ARGs (%)

	Tetracycline	Sulfonamides	Quinolones	Macrolides	Total
SAC	99.9966	43.2817	99.2899	98.1428	99.9809
ASPC	99.9981	$\boxed{-4543.6148}$	40.9158	$\boxed{-365.7604}$	99.9375
DPC	99.9972	$\boxed{-8534.6921}$	$\boxed{-837.3011}$	$\boxed{-4425.4586}$	99.9700
MC	99.9586	$\boxed{-5.3452}$	94.1729	$\boxed{-13.5479}$	99.6831

(Zhao *et al.*, 2022)

Vermicomposting and black soldier fly larvae

Vermicomsposting

https://www.ontario.ca/page/vermicasting-or-vermicomposting

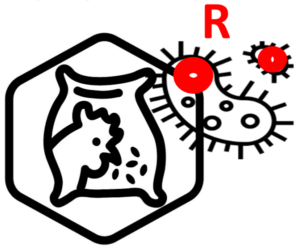
Black Soldier Fly Larvae

https://www.thenationalnews.com/uae/science/meet-the-black-soldier-fly-the-new-weapon-in-the-war-against-food-waste-1.761140

End Products

Bio fertilizer

Bio fertilizer



Feed

Parameters to optimize For better ARGs removal

Agricultural waste co-composting
Enforced aeration
Functional microbial inoculum-feeding

Modulating initial larvae density
ARGs in larvae deserve better attention

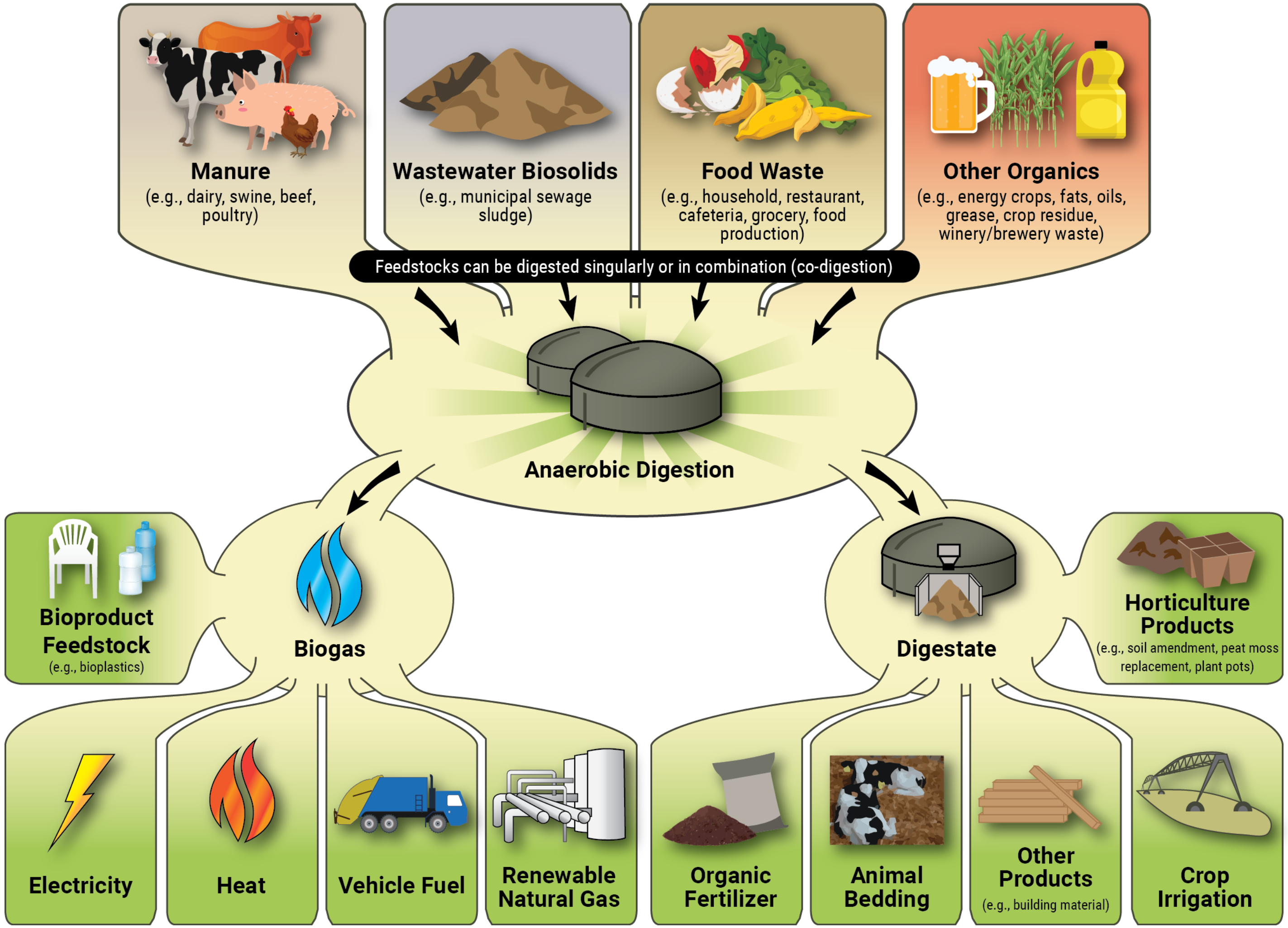
Both processes give good results for ARGs removal. Possible optimizations

Anaerobic digestion (AD)

- In the AD process, organic matter is degraded anaerobically by a variety of microorganisms working in synchrony

- Several studies showed that digestate of AD contain AM residues, ARB and ARG
- ARGs :1 $\times$ 10^3 to 2.3 $\times$ 10^6 copies/g of digestate (Wolak *et al.*, 2023)
- ABR: bacterial species resistant to 11 antibiotics out of 12 (Sun *et al.*, 2020)

- Most parameters have been optimized to increase biogas yield. Trade-off with ARGs removal (Haffiez *et al.*, 2022).



From EPA

Anaerobic digestion (AD)- ARGs removal

Organic wastes

Anaerobic digestion

Bio fertilizer

+ ENERGY (Electricity, fuel)

Liquid and solid fraction

Pre-treatments
Data on Sludge
Ozone ↓ (13 to 25%)
Alkali ↓ (13 to 25%)
Free nitrous acid ↓ (up to 74%)

Enzymatic treatment ↓ (up to 25%)
Fungal mash ↓ (up to 94%)
except ↑ bla_{TEM} (19%)

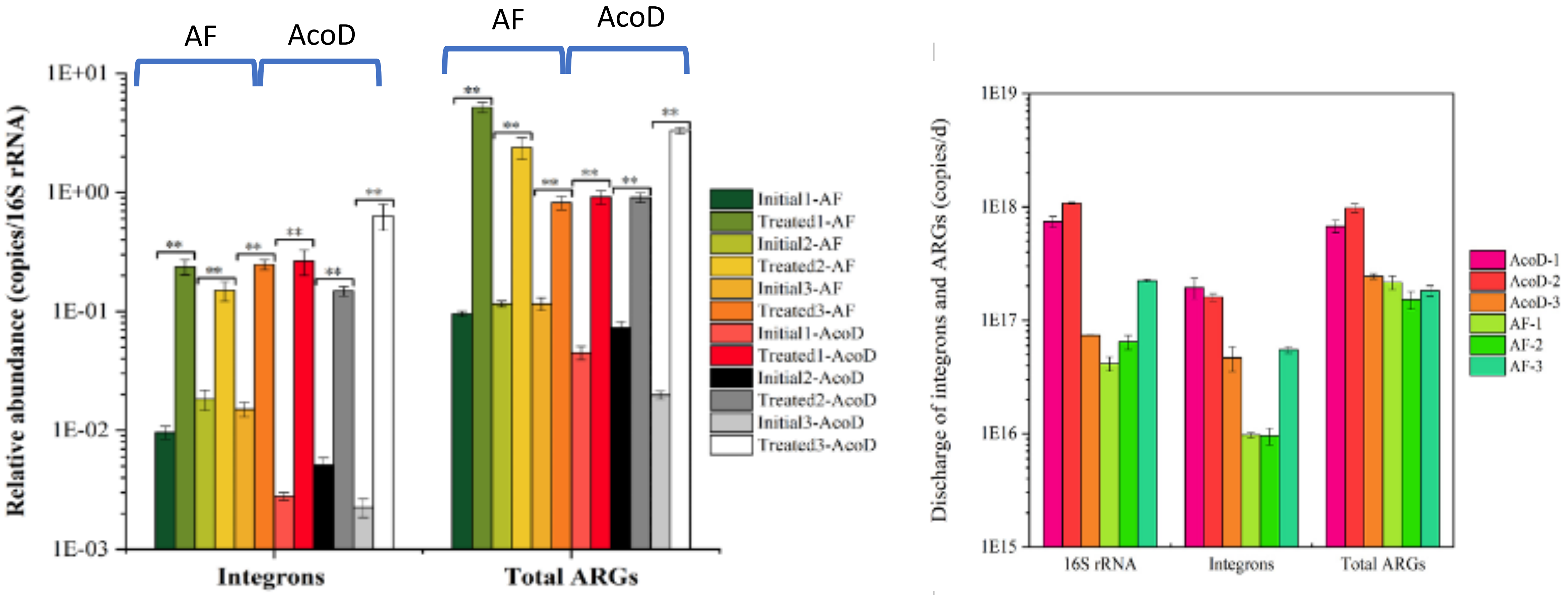
Temperature
(55°C) ↓ 86.6 % versus (35°C) ↓ 31% Very dependant of the feedstock; on manure thermophilic conditions could favor both pathogens and HGT.

Co-digestion with sludge, manure or straw
Anitbiotic residues in sludge and manure could impact AD and ARGs removal

Two stages (acidogenic- methanogenic) ↓

Additives
Nanoscale zero valent iron (nZVI) ↓ Activated Carbon ↓↑

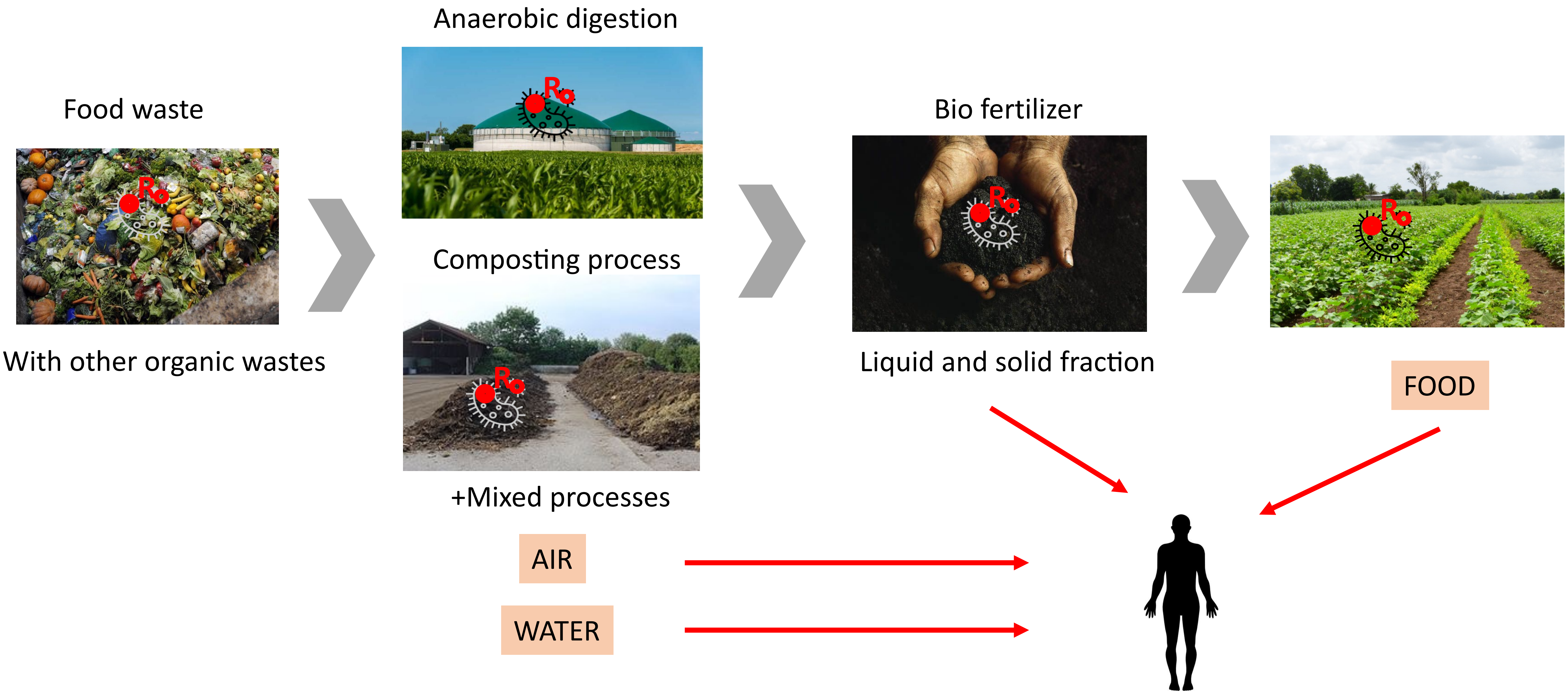
Composting (AF) versus anaerobic digestion (AcoD)



(Wang *et al.*, 2020)

Both aerobic and anaerobic biotreatment could increase relative abundance of FW's ARGs, and the discharge of ARGs from treated FW posing potential threats to receiving environments.

Biotransformation processes and AMR spreading

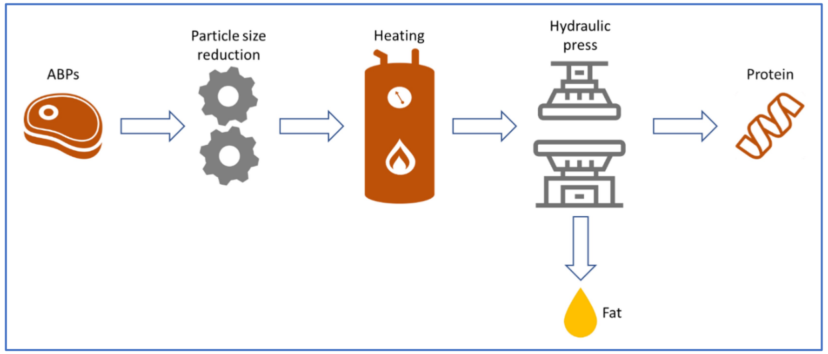


Other food waste management processes

https://www.farmersweekly.co.za/

Conversion of food waste for pet food and animal feed

- Raw food
- Rendering (feed ingredients)
- Fish silage
- …



Zagklis et al. 2020

For bacterial biomass production

- Food waste use as substrate for bacterial growth

https://www.cam.ac.uk/research/news/

Lack of specific data on AMR
Various heat/pressure treatments should kill bacteria and remove ARGs
Regulation on animal by products (i.e.: EU)

Landfills and open dump

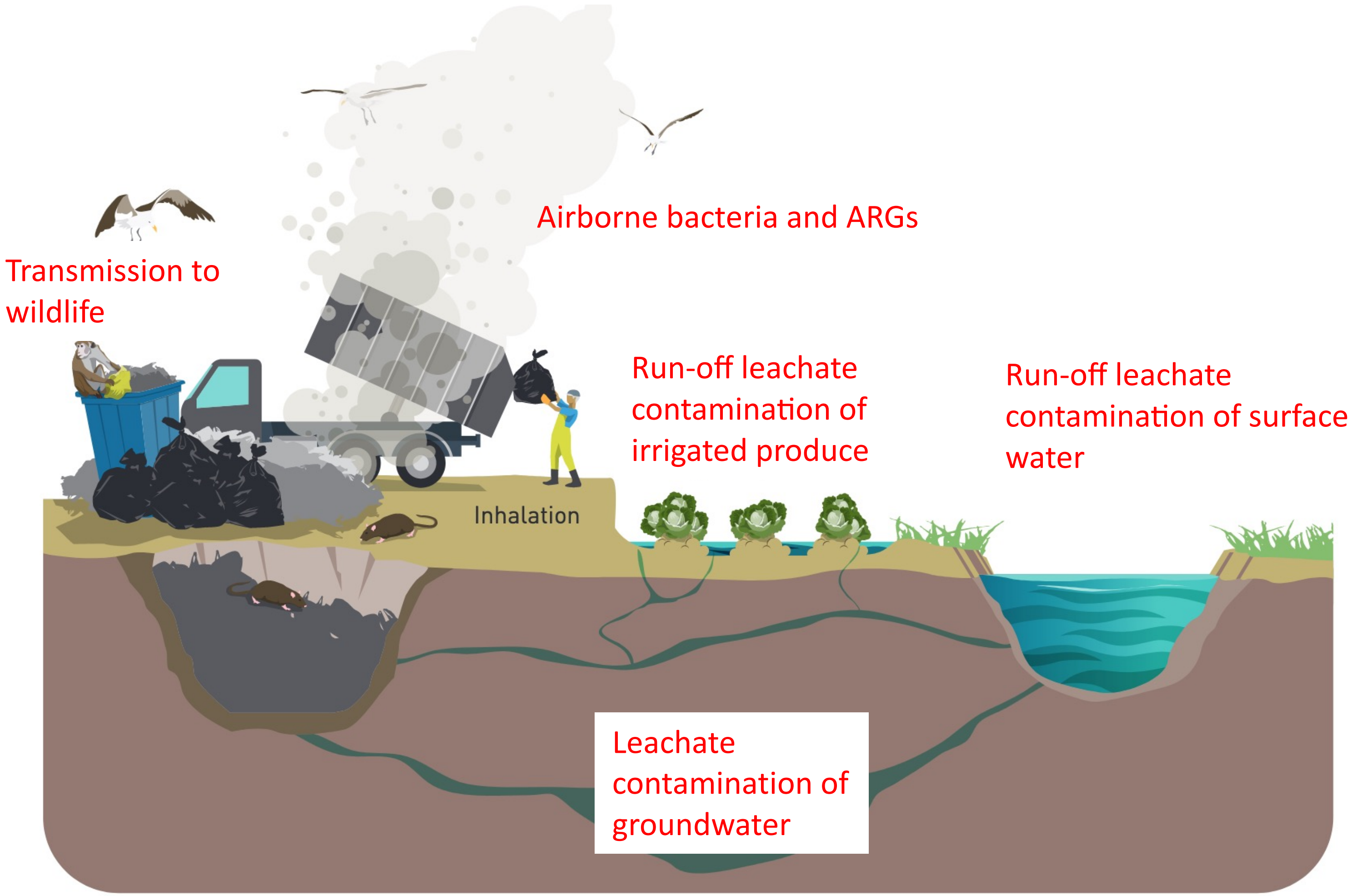
- **Good conditions for bacterial growth**: FW represents an important part of municipal solid waste landfills from 20 up to 65% of the overall waste found in municipal landfills (Pham *et al.*, 2015) (Ding *et al.*, 2021).

- **Co-selection and co-resistance**: FW could be mixed with multiple chemicals and biological substances that are well known to favor selection and HGT of ARGs: heavy metals, microplastics, antiseptic/antimicrobials. Co-selection and co-resistance
- **Antibiotic concentration** in leachate-borne antibiotics could be found at the µg/L level, in the MSW landfills in China (Wu *et al.*, 2022a)(Anand *et al.*, 2021), in Italy (He *et al.*, 2021)

- **Type of landfills**: Older landfill more prone to leachate – ARGs around 5.5-6.8 × 10^5copies/µL leachate, in Italy banned antibiotic still present (He *et al.*, 2021).

- **FW in landfill contributes to greenhouse gas emissions**. Climate change could exacerbate the AMR threat.

Landfills-routes of AMR spreading



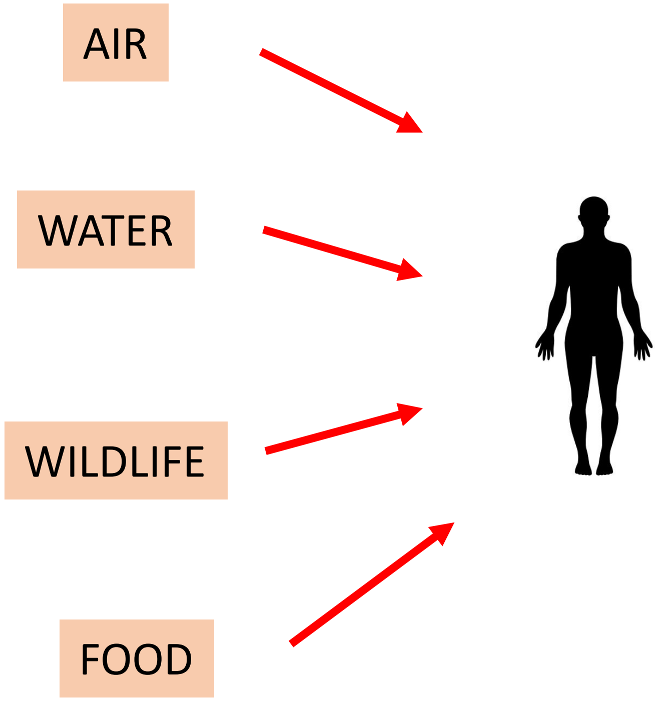


Figure 18

Potential AMR transmission pathways from landfills

Bracing for Superbugs: Strengthening environmental action in the One Health response to antimicrobial resistance. UNEP. 2023

Gaps

- Lack of data of FLW/AMR compare to other organic wastes (manure, sludge)
- Evaluation and optimization of FLW biotransformation processes to reduce ARGs
- Tracking AMR from bio-transformed products to soil, plant, animals up to humans (risk assessment)

Limitations

- Food loos/waste sources vary considerably
- Biotransformation processes are also very variables (pre-treatment, mono or co composting/AD, volumes, time, parameters)- Biotransformation processes are performed at local, individual on small volume (uncontrolled) up to industrial levels.
- Methods to measure and report ARGs and ARB could also vary from one study to another

Conclusions- discussion

- Food loss and waste is a neglected source of AMR
- Biotransformation processes might not lead to sufficient ARGs removal
- There is a potential risk associated with the use of by-product from FLW
- More research on AMR fate in FLW is needed
- Optimization of food waste management processes to remove ARB/ARGs
- Protocol validation
- Inform on best practices

- The best prevention remains
  - Reduction of food loss and waste
  - Reduce antimicrobial use

Thank you for your attention