ENVIRONMENTAL PERFORMANCE OF WASTE-TO-ENERGY IN PROMOTING SUSTAINABLE FOOD WASTE MANAGEMENT

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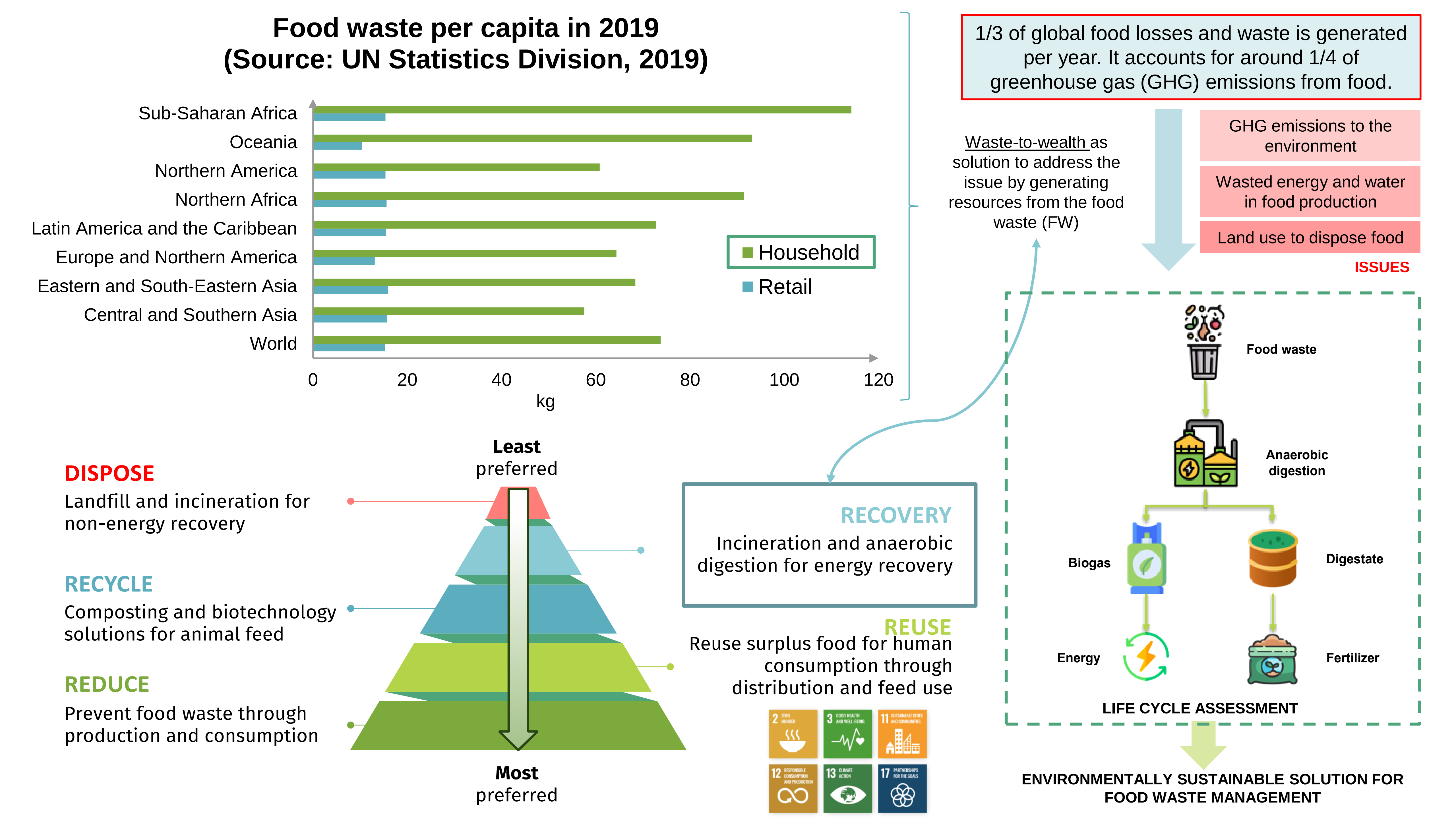
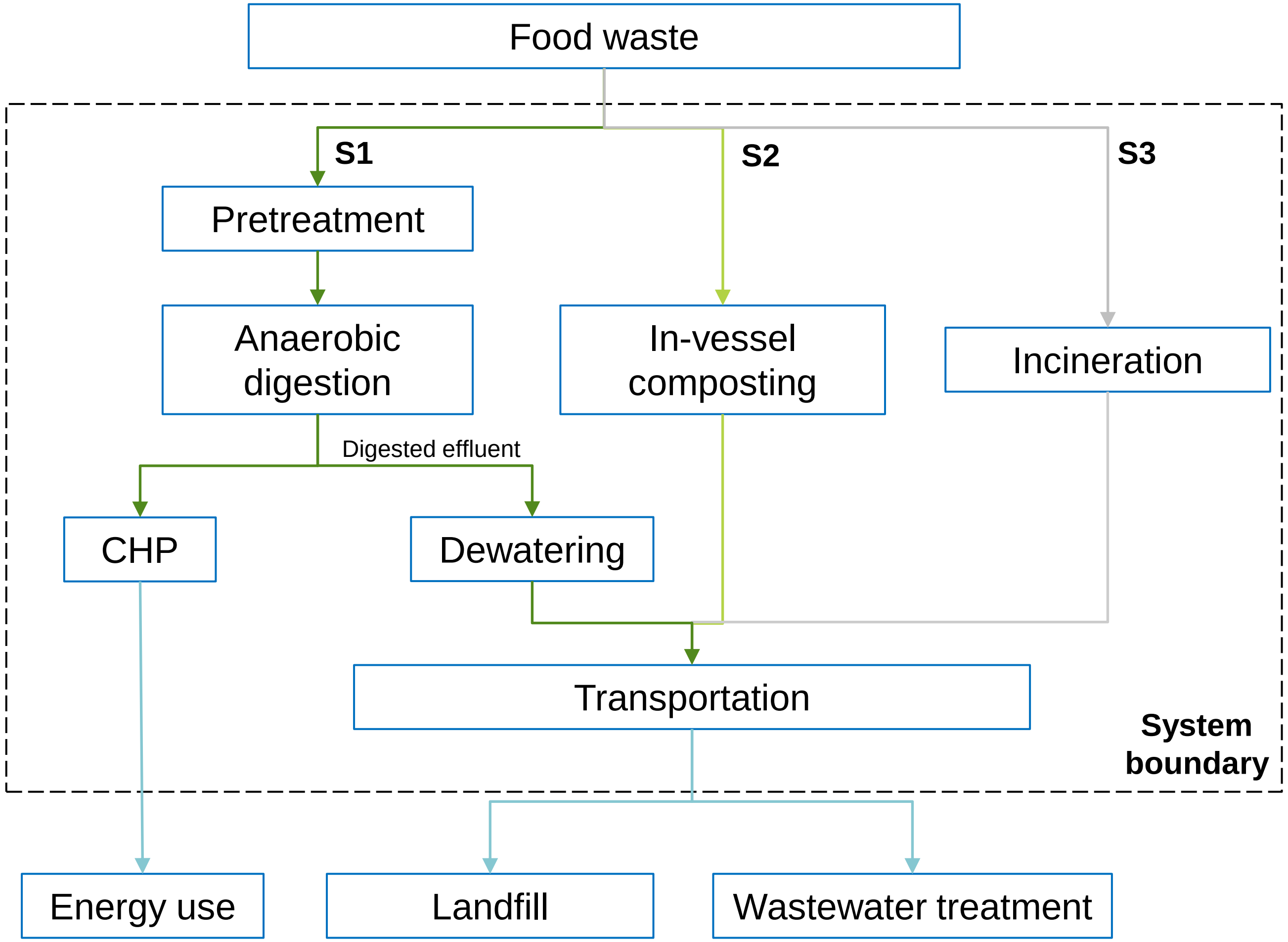

Food waste per capita in 2019
(Source: UN Statistics Division, 2019)
Sub-Saharan Africa
Oceania
Northern America
Northern Africa
Latin America and the Caribbean
Europe and Northern America
Eastern and South-Eastern Asia
Central and Southern Asia
World
0
20
40
60
80
100
120
kg
Household
Retail
1/3 of global food losses and waste is generated per year. It accounts for around 1/4 of greenhouse gas (GHG) emissions from food.
Waste-to-wealth as solution to address the issue by generating resources from the food waste (FW)
GHG emissions to the environment
Wasted energy and water in food production
Land use to dispose food
ISSUES
Food waste
Anaerobic digestion
Biogas
Digestate
Energy
Fertilizer
LIFE CYCLE ASSESSMENT
ENVIRONMENTALLY SUSTAINABLE SOLUTION FOR FOOD WASTE MANAGEMENT
Least preferred
DISPOSE
Landfill and incineration for non-energy recovery
RECYCLE
Composting and biotechnology solutions for animal feed
REDUCE
Prevent food waste through production and consumption
Most preferred
RECOVERY
Incineration and anaerobic digestion for energy recovery
REUSE
Reuse surplus food for human consumption through distribution and feed use

Previous studies on LCA for biogas production from food waste across the world

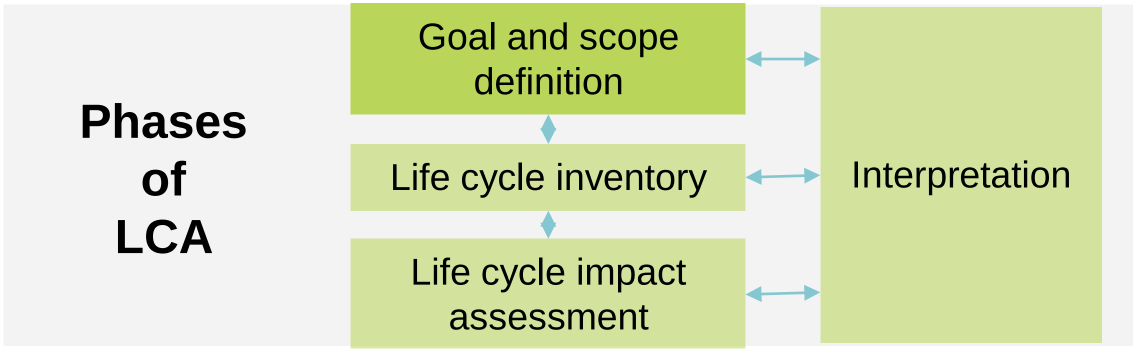
Country (Reference)	LCA software and methodology	Functional unit	Impact categories assessed	Technologies
Singapore [1] (Tian et al., 2021)	Gabi 8.7, EcoInvent	1 ton of FW generated from local food center	GWP, PMFP, FFP, WCP, SOP, IRP, ODP, EOFP, HOFP, HTPc, HTPnc, METP, MEP, TETP, TAP	S1: FW incineration S2: Decentralized AD (electricity generation) S3: Decentralized AD (biogas - cooking fuel) S4: Centralized AD (electricity generation) S5: Centralized AD (transportation fuel production)
Italy [2] (Bartocci et al., 2020)	OpenLCA	Providing electricity (reference flow of 1 kWh electricity produced)	CC	AD of FW
Sweden [3] (Brunklaus et al., 2018)	OpenLCA	1 ton of processed FW (dry mass)	GWP, AP, EP, HTP, NREU, REU	S1: FW to biogas S2: FW to SA S3: Corn to SA
Australia [4] (Opatokun et al., 2017)	SimaPro 8.0, ReCiPe	1 kg of FW	CC, ODP, TAP, FEP, MEP, HTP, POCP, PMFP, TETP, FETP, METP, WCP, SOP, FFP	S1: AD only S2: Pyrolysis and AD S3: Pyrolysis only
China [5] (Woon et al., 2016)	SimaPro 7.2.4, ReCiPe 1.04	1 ton of FW (wet basis)	CC, PMFP, TAP	S1: FW to electricity and heat S2: FW to city gas S3: FW to biogas fuel for vehicle use



Life Cycle Assessment SimaPro

Method based on ISO 14000, 14040	
Goal of study	To assess the environmental performance of generating biogas from food waste
Functional unit (FU)	1 ton of food waste
Boundary of study	Gate-to-gate
Software for analysis	SimaPro v9
Inventory data	Foreground: Secondary data, Background: EcoInvent v3 database
Calculation method	ReCiPe 2016
Approach	Midpoint (18 impact categories), Endpoint (3 endpoint categories)

Food waste composition [6]	Amount	Unit
Moisture content	84.97	%
Protein	20.45	%
Fat	29.3	%
Organic matter	89.53	%
Impurity rate	7.95	%
Oil content	3.02	%



Inventory Data

Anaerobic digestion

Materials[6]	Amount	Unit
Input		
Food waste	1	ton
Tap water	2.6	ton
Municipal waste collection lorry	20	tkm
Electricity	22.22	kWh
Output		
Biogas	385.93	kWh
Oil	0.029	ton
Sewage	0.069	kg
Wastewater	1	ton
Impurities	0.08	kg
Biogas residues	0.097	ton
Ammonia	0.24	kg
Hydrogen sulfide	0.0082	kg
Methane	0.072	kg
Carbon monoxide	0.15	kg
Sulfur dioxide	0.078	kg
Nitrogen oxides	0.047	kg
Non-methane volatile organic compounds (NMVOC)	0.0062	kg
Platinum	0.022	kg

Composting

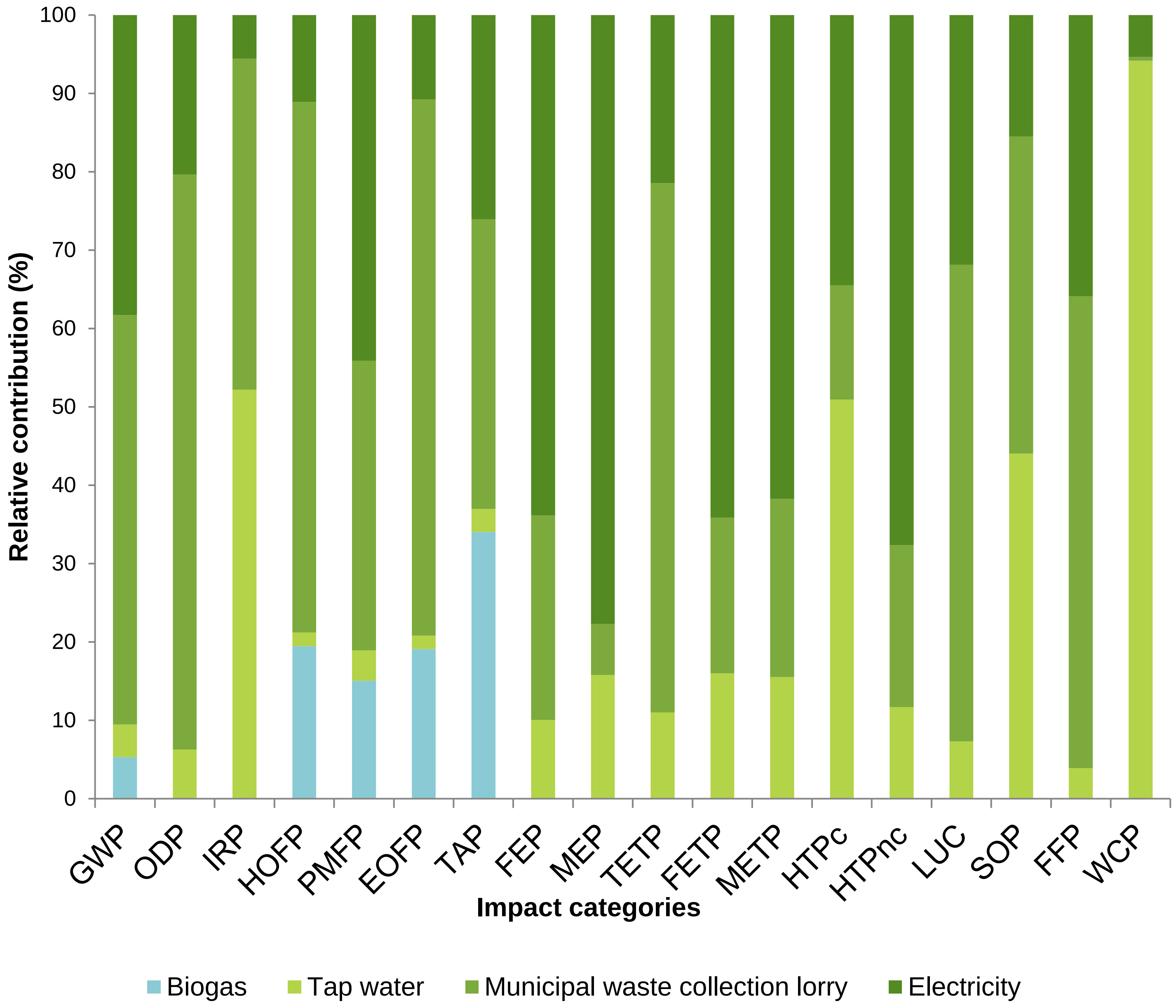
Materials[6]	Amount	Unit
Input		
Compost	300	kg
Sulfuric acid	2.1	kg
Sodium hydroxide	0.1	kg
Electricity	93	kWh
Energy from diesel	21	MJ
Municipal waste collection lorry	20	tkm
Heat from steam	0.07	MJ
Output		
NMVOC	0.31	kg
Methane	0.62	kg
Ammonia	4.42	kg
Ammonium nitrate	3.3	kg
Potassium	6.5	kg

Incineration

Materials[7]	Amount	Unit
Input		
Electricity	92.7	kWh
Compost	300	kg
Sulfuric acid	2.1	kg
Sodium hydroxide	0.1	kg
Ammonia	0.4	kg
Chromium oxide	0.25	g
Sodium hydroxide	0.5	kg
Hydrochloric acid	0.59	g
Quicklime	4.2	g
Iron (III) chloride	0.33	g
Municipal waste collection lorry	20	tkm
Output		
Electricity	255	kWh
Natural gas	11.7	kWh
Ammonia	6.8	g
Carbon monoxide	0.22	kg
Methane	6.4	g
Nitrogen oxides	0.27	kg
Sulfur dioxide	5.8	g
Particulates	0.063	kg
Heavy metals	0.44	mg
Nitrate	0.42	kg
Sulfate	4.1	kg
Phosphate	0.027	kg
Heavy metals	4.8	mg

Environmental Performance of Anaerobic Digestion

Midpoint Approach



The process of anaerobic digestion affected global warming at 48.76 kg CO_2-eq/ton of FW mainly contributed by the municipal waste collection lorry

The production of biogas impacted the production of ozone formation, terrestrial acidification, particulate matter and global warming due to the gases being emitted into the air. This includes gases such as methane, carbon monoxide and sulfur dioxide

Electricity based on Malaysia's grid energy mix impacted marine eutrophication (MEP) the most as it's energy mix is highly reliant on coal. Coal has a high EP due to the mining process that releases significant amounts of phosphate to wastewater [8]

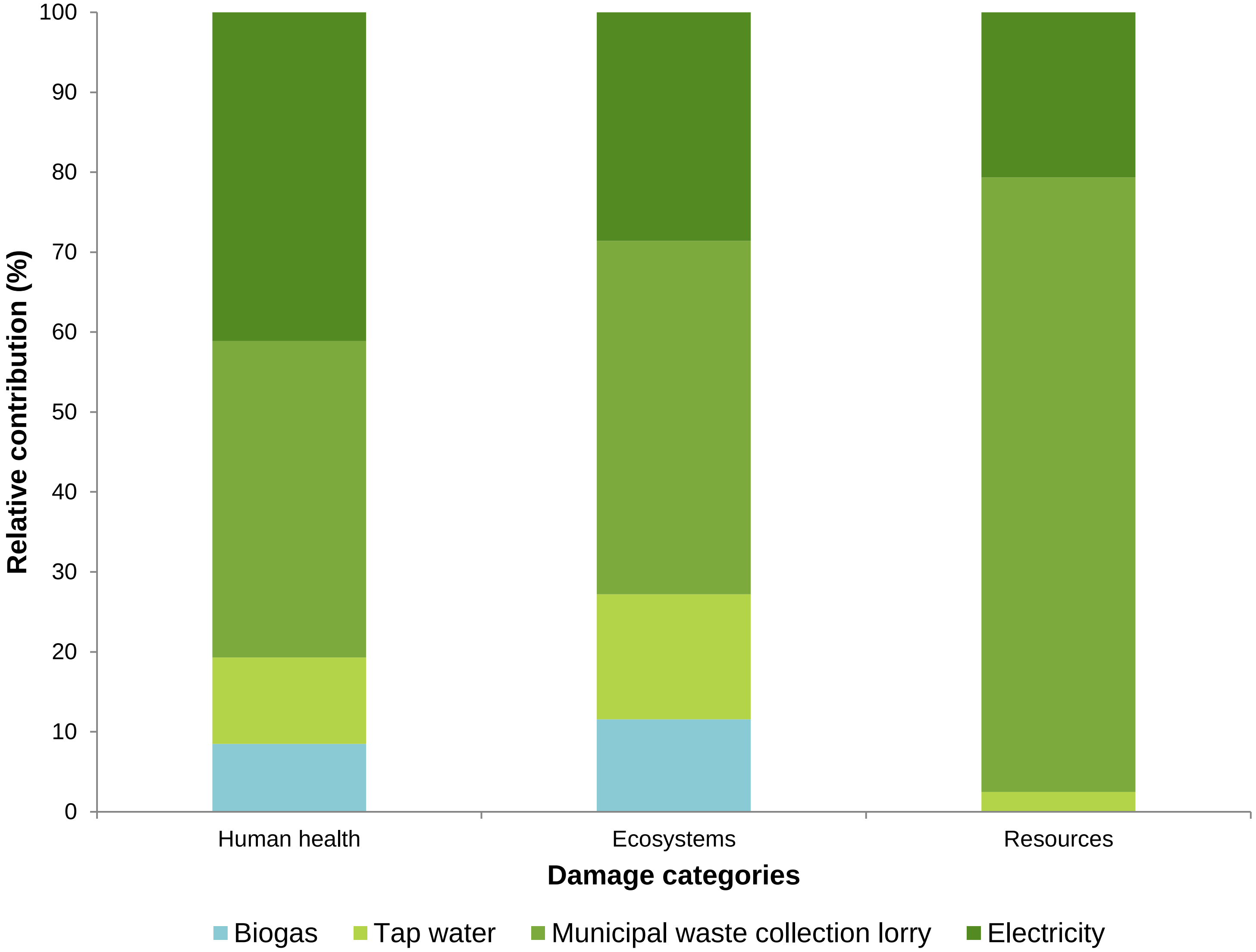
Environmental Performance of Anaerobic Digestion

Endpoint Approach

Overall, the anaerobic digestion impacted human health, ecosystems quality and resources availability at 1.30 x 10^{-5} DALY, 2.74 x 10^{-7} species·year and 4.67 USD 2013 respectively

The municipal waste collection lorry exclusively impacted 5.14 x 10-5 DALY, 1.21 x 10-7 species·year and 3.59 USD2013

Similar findings with [9] which showed that the high potential impacts were from the transportation of raw materials and the consumption of electricity during AD process.



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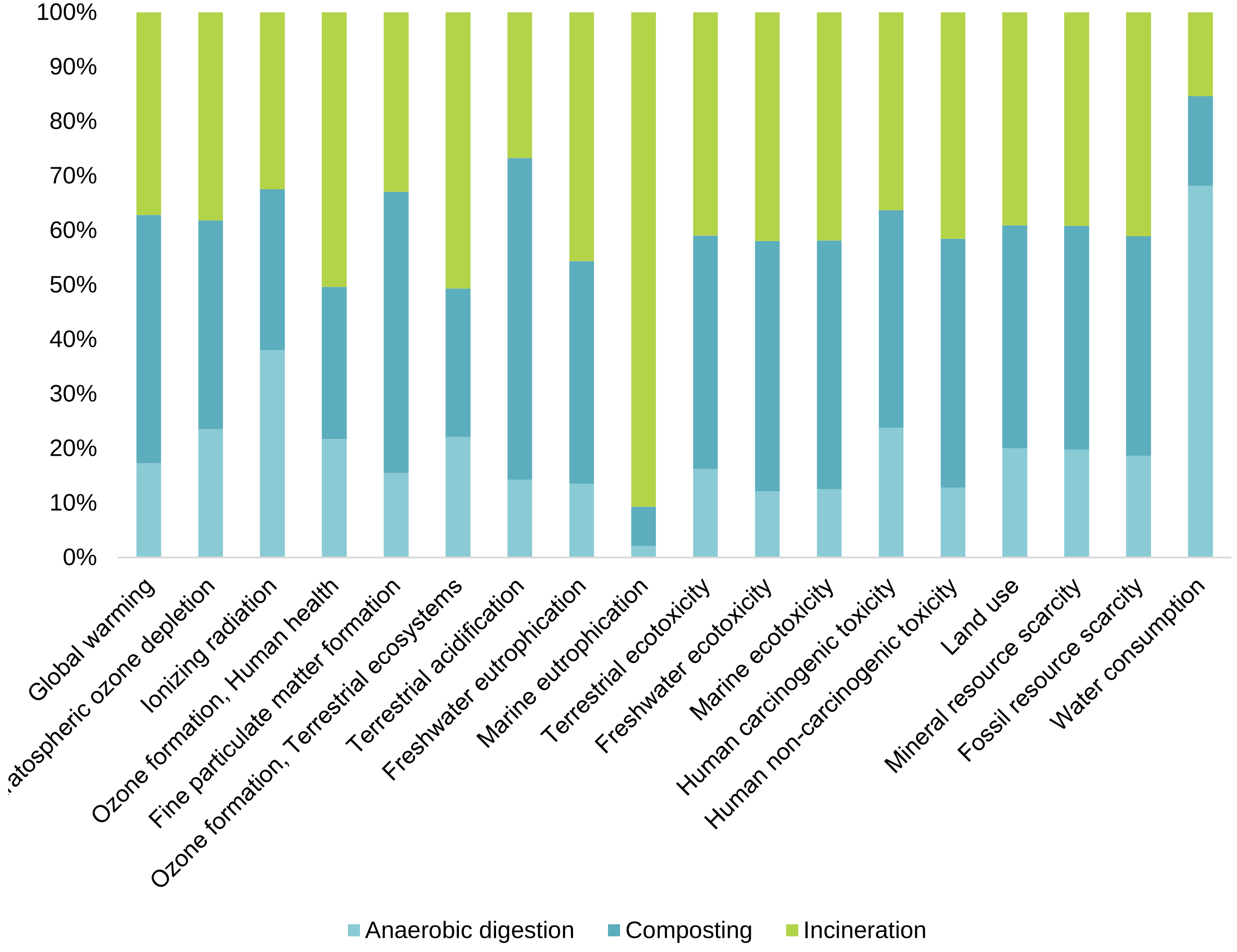
Environmental Performance of Different Treatment Method

Midpoint Approach



In-vessel composting is shown to have the worse environmental impacts compared to anaerobic digestion and incineration across 11 impact categories such as global warming (128.51 kg CO_2-eq) and human toxicity potential (3.56 kg 1,4-DCB).

Incineration mainly affected the photochemical oxidant formation and eutrophication potential but impacted global warming at 104.94 kg CO_2-eq

Anaerobic digestion performed the best across all impact categories except for ozone depletion, ionizing radiation and water consumption potential which it performed the worse.

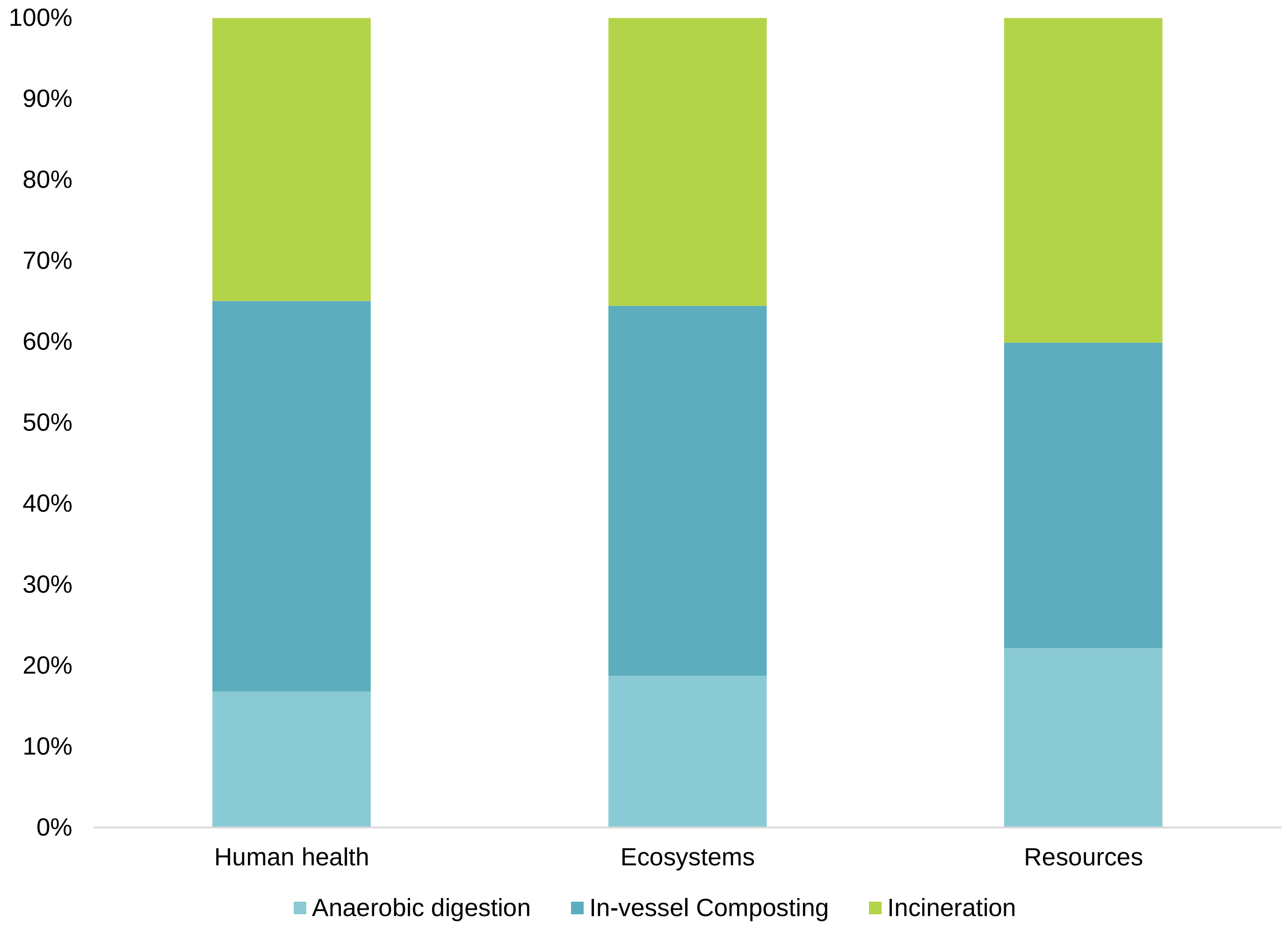
Environmental Performance of Different Treatment Method

Endpoint Approach

In-vessel composting affected both human health (3.73 x 10^{-4} DALY) and ecosystems (6.67 x 10^{-7} species.yr) compared to anaerobic digestion and incineration but affected resources availability (7.96 USD2013).

Incineration had the highest impact on resources availability (8.45 USD2013) due to the combination of numerous chemical usage, large electricity consumption and the transportation needed for the process.

Anaerobic digestion only affected human health and ecosystems quality and resources availability at 1.30 x 10^{-4} DALY, 2.74 x10^{-7} species.yr, and 4.67 USD2013, respectively.



Conclusion and Future Outlook

Effective approaches to lessen the negative effects on the environment includes improving biogas generation capacity, increasing power generation efficiency, optimizing Malaysia's energy structure, and lowering electricity use during treatment stage.

The impact of anaerobic digestion and in-vessel composting arises mainly from energy consumption, greenhouse gas emissions (i.e., N2O, VOC), and landfilling of residues similar to the findings of [10].

With both midpoint and endpoint approaches factored in, the best-to-worst scenario can be deduced as such from this study:
S1 > S3 > S2

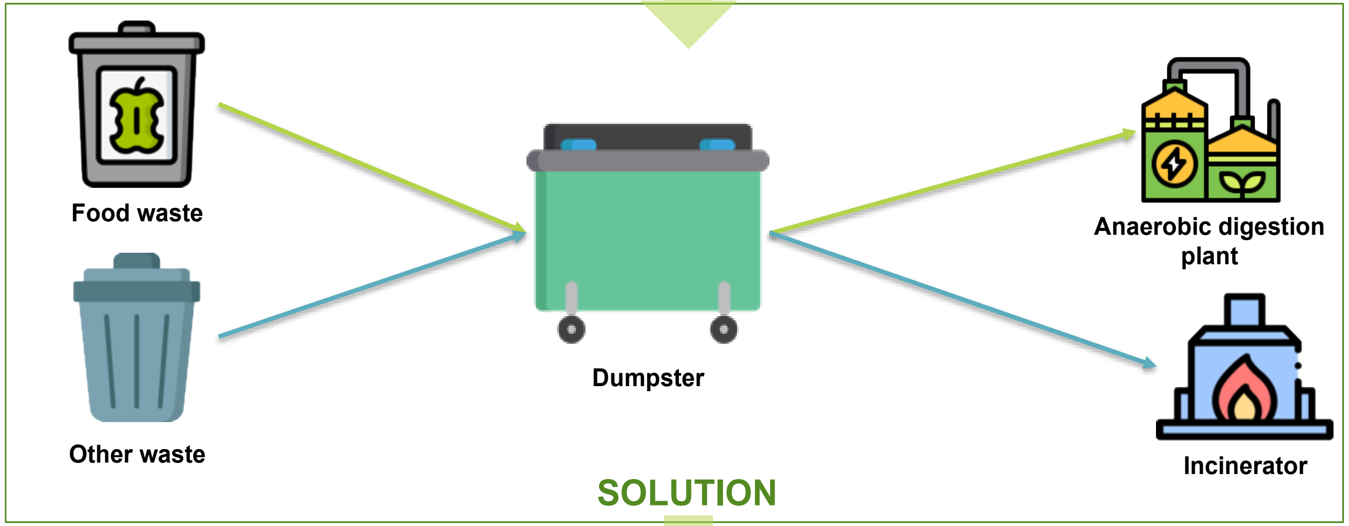
Food waste management issues and proposed solution [11]

Source segregation uncommon in Malaysia and discarded with other municipal solid waste

- Door-to-door collection services
- Burial, open burning, illegal dumping

- Open landfill
- Sanitary landfill
- Composting (small scale)
- Livestock feed

PROBLEM



Development of a National Strategic Plant for Food Waste Management

THANKS!

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