**Supplementary Materials:**

# Assessing Greenhouse Gas Emissions and Energy Efficiency of Four Treatment Methods for Sustainable Food Waste Management

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**Table S1-1** Literatures with the detailed explanations

| Cases studied region | Aims of the study | Scenarios description | Findings | Source |
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| Sweden | To make a statement about which of the compared systems is more advantageous from an environmental perspective, and the conditions under which this is true | 1. Food waste disposer + anaerobic digestion<br>2. Food collected for anaerobic digestion | Food collection performed lower assessment from food waste disposer | Bernstad Saraiva et al., [65] |
| Hong Kong, China | To comparatively investigate the co-digestion consortia on their phylogeny structures in the key function guilds of fatty acids and methane metabolism | Food waste + anaerobic digestion | The co-digestion of food waste with sewage sludge was applicable with both satisfying methane yield and the VS reduction ratio | Wang et al., [10] |
| Suzhou, China | To summarize some of the challenges involved in the food waste treatment facilities | The proteins in the food waste is used for protein feed additives, the rest is for long-term anaerobic fermentation | The results indicate that the plant has strong environmental and economic performances, suggesting that future pilot scale and full scale projects in both China and abroad can draw lessons from its operation | Wen et al., [8] |

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| Hong Kong, China | To determine the environmental impacts associated with the Smart-Food Waste Recycling Bin (S-FRB) technology and identify environmental hotspots to reduce the impacts. | The S-FRN system with onsite compost are compared with food waste for landfill, and food waste for anaerobic digestion | Compared with pilot study, the operation of S-FBR at full capacity significantly reduces the amount of greenhouse gas emissions generated. | Yeo et al., [17] |
| Singapore | A cost-benefit analysis would be conducted to compare several food waste schemes with the existing incineration-based scheme considering both private and environmental costs. | Two decentralized gasification-based waste disposal schemes are proposed. | It was found that the gasification-based schemes are financially superior to the incineration-based scheme. | You et al., [18] |
| China | Two full-scale food waste plants are compared using life cycle assessment, carbon flow analysis, energy flow analysis, and economic assessment. | Single-phase anaerobic digestion (SPAD) and two-phase anaerobic digestion (TPAD) are compared based on two full-scale food waste treatment plants | The plant using SPAD process with thermal pre-treatment gets 8% higher biogas yield and recovers some waster oil for biodiesel production. | Yu et al., [19] |
| Hong Kong, China | A plant-wide COD-based transformation model was established to profile the | Integrated FW and wastewater management were comprehensively evaluated through analyzing the local | Estimated secondary effluent in the biological WWTPs with the FW addition could satisfy the | Zan et al., [15] |

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| | transformation of food waste (FW) in the biological wastewater treatment plants (WWTPs). | biological WWTPs network and local first-hand data of FW in Hong Kong | discharge standard in Hong Kong; Energy consumption and operational cost in the WWTPs are highly dependent on the treatment processes and the penetration rates of FWDs; diverting FW into wastewater treatment on a city scale, favoring the policy-making on FW management in different metropolise. | |
| Shenzhen, China | The aim of this study was to determine the quantity, composition of avoidable household food waste (HFW), driving forces behind HFW generation and possible strategies to reduce the amount of HWF generated. | A survey was conducted during April to July 2017 in Shenzhen City (Guangdong Province, southern China) to identify major drivers of HFW. | HFW prevention can yield great environment benefits by reducing carbon emissions, and both household size and income are the major drivers to HFW generation. A substantial reduction in HFW generation can be achieved through improvements in consumer behaviors, consciousness and attitudes. | Zhang et al., [51] |

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| Aarhus City, Denmark | The purpose of this analysis is to deliver decision support regarding whether (i) the installation of food waste disposers in private homes (AS1) or (ii) separate collection and transport of organic waste to biogas plants is a more viable environmental and economic solution (AS2). | AS1: 16% of the organic fraction of the domestic organic waste (D-OF) dry weight is ground in FWDs in private households and transported via the collective sewer system to Egaa and Marselisborg WWTP; AS2: Two versions of AS2 were modelled diverting, respectively, 16% (AS2a) and 100% (AS2b) of the D-OF away from incineration, by separate collection and transport by trucks to biogas plants at Egaa and Marselisborg WWTP. | AS2b has the best environmental performance when looking at the mitigation of freshwater utrophication (FE), climate change (CC), and carcinogenic human toxicity (HTc). When looking at fossil depletion (FD), marine eutrophication (ME), terrestrial ecotoxicity (TE), and non-carcinogenic human toxicity (HTnc), the reference scenario performs better than alternative scenarios. When looking at the human toxicity results from ReCiPe, a similar performance is obtained for all scenarios. | Thomsen et al., [12] |
| South Korea | The objectives of this study were to evaluate and compare different food waste disposal systems from generation to final disposal with environmental aspects including | Food waste for dry feeding, wet feeding, composting, and landfilling compared. | The results showed that about 609 kg $CO_2$-eq/f.u. of greenhouse gases would be produced from dry feeding, 1420 | Kim and Kim [66] |

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| | global warming using life cycle approach | | kg $CO_2$- eq/f.u. from wet feeding, 910 kg $CO_2$-eq/f.u from composting, and 912 kg $CO_2$-eq/f.u. (base line) from landfilling, if the by-products were incinerated. If the by-productswere landfilled, about 746 kg $CO_2$-eq/f.u. of greenhouse gases would be produced from dry feeding, 790 kg $CO_2$- eq/f.u. from wet feeding, 843 kg $CO_2$-eq/f.u. from composting, and 912 kg $CO_2$-eq/f.u. (base line) from landfilling. | |
| Singapore | The main objective of this study is to compare the three technologies, i.e. incineration, AD and FWEB system in Singapore's context from an environmental perspective in terms of acidification potential (AP), eutrophication potential (EP), global warming potential in 100 years (GWP100), and cumulative energy demand (CED) to help | Food waste are treated by incineration, anaerobic digestion (AD), and food waste-to-energy biodiesel technic (FWEB). | The LCA results have shown that FWEB is favoured for FW with OC > 5% and AD for OC ≦ 5%, under the assumptions made in this study. The results have shown that AD is the best choice if applicable in the local environment. Otherwise, FWEB is the preferred | Ahamed et al., [67] |

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| | identify an appropriate FW management method for urban societies. | | choice over incineration. | |
| Uppsala, Swedish | The objective of this study was therefore to compare the outcome, with regard to greenhouse gas emissions, of different food waste management scenarios available to supermarkets in Uppsala. The overall aim was to provide more detailed knowledge about the quantity of emissions avoided when applying a more prioritised step in the waste hierarchy for the management of food waste. | Six food waste management scenarios: landfill, incineration, composting, anaerobic digestion, animal feed and donations, using five food products (bananas, grilled chicken, lettuce, beef and bread). | The greatest potential for reducing greenhouse gas emissions was in the bread waste stream, since bread is an energy-rich product with a relatively low carbon footprint, increasing the possibilities for replacing fossil energy carriers. Lettuce, with its high water content, had the least potential to reduce greenhouse gas emissions when the waste management method was changed. Waste valorisation measures should therefore focus on food products with the potential to replace production of goods and services, rather than on food products that are wasted in large quantities or have a high carbon footprint | Erikkson et al., [68] |
| Southern Sweden | The present paper reports the potentials for household food waste prevention | The groups for different food types used were: Meat, Bread, Prepared food, | The study clearly shows that although modern alternatives for food waste | Bernstad Saraiva Schott and Andersson [69] |

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| | based on a case study in southern Sweden. | Dairy products, Fruits and vegetables and Other. The lifestage categories used were: Unopened packaging, Opened packaging, Half-eaten food (unprepared left-overs, for example half-eaten apples), Prepared food (food which had been cooked/fried etc. before being discarded, for example cooked pasta or fried meat), Non packaged whole vegetables/fruits (for example whole, uneaten apples), Other meat (unprepared) and Other avoidable food (mostly candy, potato chips and popcorn). | treatment can result in avoidance of global warming potential through nutrient and energy recovery, food waste prevention yields far greater benefits for GWP compared to both incineration and anaerobic digestion. | |
| Lebanon | To integrate solid waste and wastewater management processes under a single framework | Food waste is considered with wastewater management systems | This study revealed that integrating food waste disposers in a developing economy | Maalouf and EI-Fadel [70] |

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| | and test scenarios for a waste with high organic food content typical of developing economies. | | characterized with a high fraction of food waste can be a viable alternative solution to reduce emissions for carbon trading. | |
| Hong Kong, China | This work proposes a new treatment approach involving both food waste disposal and sewerage treatment called MOWFAST i.e. Municipal Organic Waste management by combined Food waste disposal and Sewerage Treatment. | Installing of food waste disposer co-treated with wastewater (MOWFAST) | This resulted in producing higher specific methane yields (7.86 L $CH_4$/kg VS added versus 0.95 L $CH_4$/kg VS added) and 1.4-fold higher cumulative methane yield over sludge AD. | Kaur et al., [71] |
| Melton, and Sutherland shire, Australia | The aim of the study was to provide decision makers with a tool to analyse and determine the most environmentally friendly waste management system for their specific waste catchment | Food waste is treated by anaerobic co-digestion, separated anaerobic digestion, and mechanical biological treatment | Anaerobic digestion based systems were shown to significantly outperform composting based systems for global warming potential (GWP). | Edwards et al., [72] |
| Not mentioned | The aims of this paper are (1) to develop a 3-stage methodology which capitalizes on the DEA + LCA framework | Food waste is compared by scenarios of anaerobic digestion, composting, anaerobic | The LCA results clearly show that no single food-waste management option performs better than the rest | Cristobal et al., [73] |

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| | proposed recently in the literature and combines data envelopment analysis, life cycle assessment and process retrofit into a single consistent framework; and (2) the application of this methodology to the assessment and retrofit of a number of technological options for food waste management. | digestion + composting, and incineration | simultaneously in all of the environmental impact categories. It is important to highlight that DEA is very sensitive to the number of attributes (i.e. impact categories) considered in the analysis. In general, increasing the number of impact categories leads to a poor discrimination (i.e. more management options are deemed efficient). | |
| New York, U.S. | The study goal was to determine if separated food waste recovery and management was environmentally sounder than waste-to-energy incineration (the baseline case). | Food waste treatment is compared with landfill, composting for agriculture application, and their combination | Results indicated that overall environmental burdens can be reduced by source separating food waste and treating it by AD, and then composting the AD residuals, or treating it with tunnel composting. Results also indicated, however, that in some impact categories, the business as usual scenario (WTE of | Thyberg et al., [74] |

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| | | residuals including food wastes) is a better choice from an environmental perspective. |

**SM-1 GHG generation and energy recovered in anaerobic digestion**

Primary and secondary sludge is mixed and dewatered before entering the aerobic digestion tank. Hydroextractor concentrates the influent COD ($S_{ti}$) to be 42 gCOD/L, meanwhile, the influent VFA ($S_{bsai}$) is measured to be 2.1 gCOD/L. The unbiodegradable fraction of the sludge ($f_{ps'up}$) is assumed to be 0.36. Based on this basic information, the hydrolysis kinetics method [60] is derived to calculate the $CH_4$ and $CO_2$ production. The methane generation is following the below steps.

$$S_{bpi} = \left(1 - f_{ps'up}\right) \times S_{ti} - S_{bsai} \quad \text{(SM.1)}$$

$$S_{upi} = f_{ps'up} \times S_{ti} \quad \text{(SM.2)}$$

The above-mentioned equations are used to calculate influent hydrolyzable COD (with symbol $S_{bpi}$ g COD/L) concentration and unbiodegradable COD concentration ($S_{upi}$ g COD/L). And the residual biodegradable COD concentration ($S_{bp}$) is calculated in following equation.

$$S_{bp} = \frac{K_s(\frac{1}{R}+b_{AD})}{Y_{AD}K_m-\left(\frac{1}{R}+b_{AD}\right)} \quad \text{(SM.3)}$$

where $K_s$ and $K_m$ are kinetic constant and considered to be 6.38 and 3.72gCOD/L, respectively. $R$ is sludge age of 15 days, $b_{AD}$ is acidogenic endogenous respiration rate and measured to be 0.041/d, and $Y_{AD}$ is pseudo acidogenic yield coefficient as 0.113 (gCOD biomass/gCOD organics hydrolyzed). So the biodegradable COD concentration ($S_{bp}$) is calculated from influent hydrolyzable COD minus residual biodegradable COD in Eq (SI.4).

$$S_{bp} = S_{bpi} - S_{bp} \quad \text{(SM.4)}$$

The acidogenic biomass concentration is estimated in Eq (SI.12), and $E$ is the fraction of biodegradable COD removed and converted to sludge mass, which is calculated in Eq (SI.5).

$$Z_{AD} = (S_{bpi} - S_{bp}) \times E \quad \text{(SM.5)}$$

$$E = \frac{Y_{AD}}{1+b_{AD}R(1-Y_{AD})} \quad \text{(SM.6)}$$

Unbiodegradable COD concentration $S_{up}$ is equal to $S_{upi}$. The total effluent COD concentration $S_{te}$ is the sum of $S_{up}$, $S_{bp}$ and $Z_{AD}$ as in Eq (SI.7).

$$S_{te} = S_{up} + S_{bp} + Z_{AD} \quad \text{(SM.7)}$$

$CH_4$ production concentration $S_m$ (g COD/L) is calculated in Eq (SI.6), where $r_h$ (g COD/L) is hydrolysis rate yielding.

$$S_m = (1 - Y_{AD})R \times r_h \quad \text{(SM.8)}$$

$$r_h = \frac{Z_{AD}}{Y_{AD}} \times (\frac{1}{R} + b_{AD}) \quad \text{(SM.9)}$$

So the $CH_4$ production $P_{CH4}$ is generated from biodegradable organic and influent VFA ($S_{bsai}$) as shown in Eq (SI.10).

$$P_{CH4} = S_m + S_{bsai} \quad \text{(SM.10)}$$

Because the $CH_4$ has a COD 64g/mol and a gas volume at ambient temperature 20° C of 22.4×(293/273) = 24 L/mol. The $CH_4$ gas production ($M_{CH4}$ g $CH_4$/L) is in the following equation, where 64 are the molecular weight for $O_2$.

$$M_{CH} = P_{CH4} \times 24/64 \quad \text{(SM.11)}$$

**SM-2 GHG and energy analysis in landfill**

GHGs from landfills were determined using the IPCC method [20], with first-order decay (FOD) used for the calculation of $CH_4$ generation. The use of FOD assumes that degradable organic carbon (DOC) in wastes decays slowly, forming $CO_2$ and $CH_4$ over a few decades. The total amount of biogenic $CO_2$ comprises three parts. The first part is the $CO_2$ generated by $CH_4$ oxidation in the upper layers of the landfill: in this study, this was set to 10% of $CH_4$. The second part is the $CO_2$ that is generated by $CH_4$ oxidation during flaring for heat or electricity generation, with the molecular weight ratio of $CO_2/CH_4$ being 44/16. The last part is $CO_2$ generated during waste decomposition: 50% of the landfill gas is assumed to be $CH_4$, and the remaining proportion is thus $CO_2$. Meanwhile, the $CH_4$ emission recovery rate is expected to be zero for the first two years, due to there being insufficient gas to operate the energy recovery equipment. From the third to tenth year, the recovery rate is 40%, while 90% $CH_4$ can be recovered from the twentieth to thirtieth years [20].

**$CH_4$ emission calculation**

To calculate the mass of decomposable DOC, the decomposable DOC (*DDOC*) is assumed to be deposited in the year *t* and was estimated as

$$DDOC_{mT} = W_i \times DOC \times DOC_f \times MCF \quad \text{(SM.12)}$$

where $DDOC_{mT}$ is the mass of decomposable DOC at year *T*, $W_i$ is the mass of waste type '*i*' deposited, $DOC_f$ is the fraction of *DOC* (0.5) that is able to be decomposed, and *MCF* is the methane correction factor, set to 1 for a managed landfill and 0.8 for an unmanaged landfill. The $DDOC_{mn\_T}$ is unreacted in deposition year *T*, and *k* is the reaction constant of 0.4 [45].

$$DDOC_{mn\_T} = DDOC_{md\_T-1} * e^{-k} \quad \text{(SM.13)}$$

The equation to calculate the mass of decomposable $DDOC_{md\_T}$ during the time frame $T$ is as follows:

$$DDOC_{md\_T} = DDOC_{md\_T-1} * (1 - e^{-k}) \quad \text{(SM.14)}$$

where $DDOC_{md\_T-1}$ is the accumulated amount at the end year $T-1$, and is calculated as follows:

$$DDOC_{ma\_T} = DDOC_{md\_T} + DDOC_{ma\_T-1} * e^{-k} \quad \text{(SM.15)}$$

The amount of $CH_4$ generated was calculated as follows, where $F$ is the volume fraction of $CH_4$, which was set to 0.5 in the produced landfill gas.

$$CH_4 = DDOCm_{ma\_T} * F * {}^{16}/_{12} \quad \text{(SM.16)}$$

The heating value of landfill $CH_4$ used in this context is 37.7 MJ/$m^3$ or 10.47 kWh/$m^3$. For heat production, the efficiency of a boiler was set to 0.8, while the efficiency of a gas turbine was modelled as 0.35 [75].