CIRCULAR HOUSEHOLD ORGANIC WASTE TREATMENT IN THE HIGH-RISE RESIDENTIAL BUILDING

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ABSTRACT

Household organic waste treatment is one of the biggest challenges in densely populated cities like Amsterdam. This problem is even more urgent in high-rise residential buildings because residents living there do not have enough organic waste bins to separate organic waste and also generally are not aware of the importance of separating organic waste. The Material Flow Analysis shows that about 97% of household organic waste in Amsterdam ends up in the centralised incineration system currently with other residual waste, which is not a sustainable treatment solution for high-rise buildings. Therefore, this research investigates three separated organic waste treatment technologies: animal feed, composting, and anaerobic digestion with case studies on six current application practices. In order to find the most appropriate and sustainable solutions to treat organic waste at its source, this research also evaluates the technical performance measures and sustainability impacts of these current practices. Lastly, this research hypothesizes a high-rise residential building in the Sloterdijk Centre area and proposes three decentralised and circular organic waste treatment scenarios within this high-rise building. Based on the preliminary sustainability impact assessment, the most preferred solution is the combination of composting, anaerobic digestion and animal feed. As a result, biogas, high-quality fertilisers and fodders are generated back for the community. More importantly, this proposed on-site organic waste treatment system can serve as a pilot project of separating and treating organic waste as valuable resources within high-rise residential buildings.

KEYWORDS: *Household organic waste, High-rise, Flow, Circular, Decentralised, Sloterdijk Centre*

I. INTRODUCTION

1.1. Research Fascination

Every one of us is producing waste every day. A large part of the waste we produce is organic waste. According to the Municipality of Amsterdam, organic waste (GFT in Dutch) refers to food waste like vegetables and fruits, and also small garden waste like flowers and plants (Gemeente Amsterdam, 2021b). Although the share of organic waste in Dutch household waste decreased from 50% in the early 1980s to approximately 31% in 2019, organic waste was still the largest part (MIE, 2021). However, organic waste is hardly separated, especially in densely populated cities. And it is known that unseparated organic waste would contaminate other recyclable waste and pose a threat to the environment and public health (Lardinois, 1993). Admittedly, how to treat organic waste properly is an urgent challenge in many big cities like Amsterdam. This research aims to approach this challenge from the perspective of architecture.

1.2. Problem Statement

The problem statement is divided into three aspects from more generic problems to the problem of the specific context that will be approached this research.

Organic waste treatment issue in high-rise residential buildings:

Four big cities (Amsterdam, Rotterdam, The Hague and Utrecht) in the Netherlands have developed rapidly over the last few decades and will account for nearly three-quarters of the Dutch population by 2030 (PBL & CBS, 2016). Naturally, overpopulation in these big cities means that more waste will be produced by their residents. Waste that is not treated properly can pose a threat to the environment and public health. But we can also treat waste as valuable resources. Meanwhile, the Dutch government has set a goal to achieve a circular economy by 2050. This circular economy term means that by 2050 raw materials will be used and reused efficiently with no more waste (MIE & EZK, 2016). Hence, efficient waste treatment to close the loop between waste and resource is a key aspect of the circular economy and has also been outlined in the National Waste Management Plan.

For low-rise buildings in these big cities, including single-family houses, row houses and duplex houses, most households have their own garbage bins to collect organic waste separately. They can even treat organic waste in their own gardens easily. Nevertheless, residents living in high-rise buildings are facing the issue of separating organic waste properly. They do not have organic waste bins to separate organic waste and also generally are not aware of the importance of separating organic waste. And high operational cost on collection and vertical transportation also makes it difficult to treat organic waste in high-rise buildings (Ori et al., 2017).

At the same time, the EU ambassadors approved new rules in 2018 to ensure that organic waste is either collected separately or recycled at source by 2023 (Council EU, 2018). Therefore, this goal is far from being achieved especially in these high-rise areas. New solutions need to be found to treat organic waste efficiently and to utilise organic waste as raw materials in high-rise areas.

The current organic waste treatment system in Amsterdam:

Taking Amsterdam as an example, one resident in Amsterdam produces 238 kilos of residual waste per year and 31% of that is organic waste (Gemeente Amsterdam, 2021a). However, most organic waste is hardly separated and will end up in the incinerators of the Waste Energy Company (Afval Energie Bedrijf, AEB) with other residual waste. Although energy is produced in this process, the nutrients in organic waste are lost, which could be used as a potential source of fertilisers and soil improvers. As a result, incineration is not an efficient method of recycling organic waste.

Recently, some areas in Amsterdam (S-buurt in Zuidoost, Geuzenveld and Java Island and Steigereiland) started to collect organic waste separately. The collected organic waste will be 100% recycled by energy companies like De Meerlanden into green gas, energy, and compost (Gemeente Amsterdam, 2021a). But this only accounts for a small part of the organic waste produced per year in Amsterdam. Furthermore, all these centralised methods of treating organic waste in waste processing companies are facing the problems of high cost on collection and transportation and Amsterdam is looking for more decentralised methods of treating organic waste at its source.

Another challenge is that residents in Amsterdam, especially in high-rise areas, are not involved in the separation of organic waste and are not aware of the importance of treating organic waste separately. However, decentralised organic waste treatment has both economic and environmental advantages and calls for greater community involvement (Adhikari et al., 2010).

Sloterdijk Centre context:

Sloterdijk Centre area is in the Nieuw-West district of Amsterdam and is in the transition from a monofunctional office area in the 1980s to a new living-working area. According to Sloterdijk Centre Vision 2040, there will be 7,500 homes for approximately 12,000 residents in 2040 (Gemeente Amsterdam, 2020). A new high-rise residential building called Vertical with 144 living units is being built in this area. It is also viable to transform the existing high-rise office building into the residential building. As a result, the new residents in the new high-rise residential building will also face the challenge of separating and treating organic waste properly.

One ambition of Sloterdijk Centre Vision 2040 is to provide an extensive network of green areas (approx. 110,000 m^2) in this dense urban context. Hence, there is a full focus on more vertical greenery and roof gardens in this area (Gemeente Amsterdam, 2020). This gives high-rise buildings the possibility to treat the organic waste at source and ultimately to utilise organic waste as valuable resources. This research will hypothesize a high-rise residential building in Sloterdijk Centre that will be renovated from an existing office building: De Knip, which is now used by Dutch tax authorities. And the objective of this research is to find the applicable on-site solutions to treat organic waste in the high rise residential building.

1.3. Thematic Research Question

The main research question is:

How to implement a circular organic waste (GFT) treatment system in the renovation of an existing high-rise office building in Sloterdijk Centre to optimise the use of organic waste as resources in 2040?

And the sub research questions are:

- What is the current situation of organic waste treatment flow in Amsterdam?

- What current organic waste treatment technologies are workable at the high-rise building level?

- How can these organic waste treatment technologies be implemented in the existing high-rise building?

II. METHOD

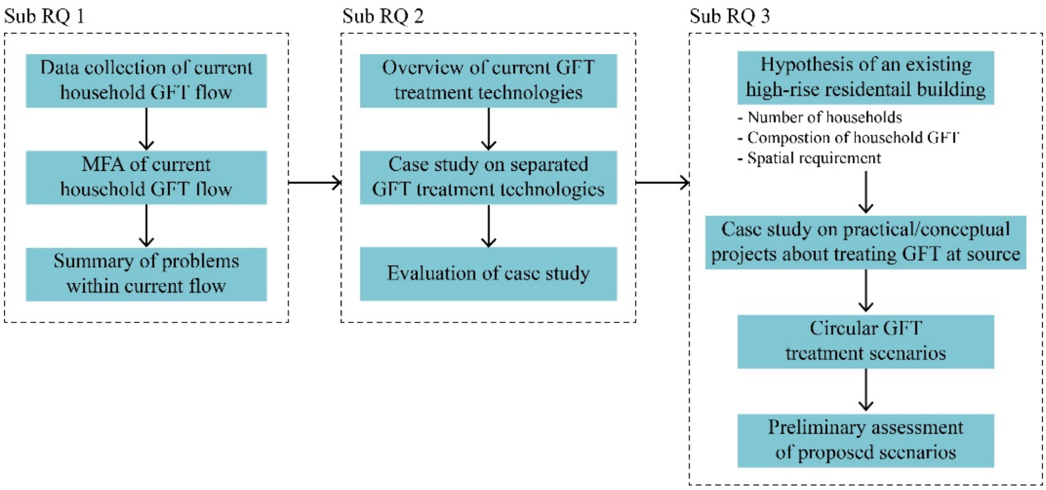

Figure 1. Research framework. Source: own illustration.

The research framework diagram (Figure 1) shows the connection between each sub research question and the structure of the whole research. To answer the first sub research question, quantitative research method like Material Flow Analysis (MFA) is used to analyse the household organic waste flow at the city scale level of Amsterdam. Relevant data on the generation of organic waste are collected from the government database. While the data on the processing of organic waste and the output of processing are collected from annual reports of waste processing companies and the interview with employees from these waste processing companies. Based on the current household organic waste flow study, there will be a summary of the problems within the current system.

Then, based on the overview of current organic waste treatment technologies with the literature review, this research will focus on the separated waste treatment technologies with the case study on some practical practices. Each case study will be investigated for the process of the treatment more in-depth. Finally, an evaluation matrix will compare the advantages and disadvantages of each case study with the same assessment indicators.

Ultimately, this research will hypothesize a high-rise residential building in Sloterdijk Centre. With this high-rise building, there will quantitative research on the number of households, the composition of household organic waste generation, and spatial requirement for organic waste treatment. At the same time, the case study is also ought to be conducted to analyse some practical or conceptual projects focusing on treating organic waste at the source. As a result, this research will propose some circular organic waste treatment flow scenarios within this high-rise residential building and give a preliminary assessment of these scenarios. The results could be concluded as the design principles for the future redesign phase.

III. RESULTS

3.1. Current household organic waste treatment flow in Amsterdam

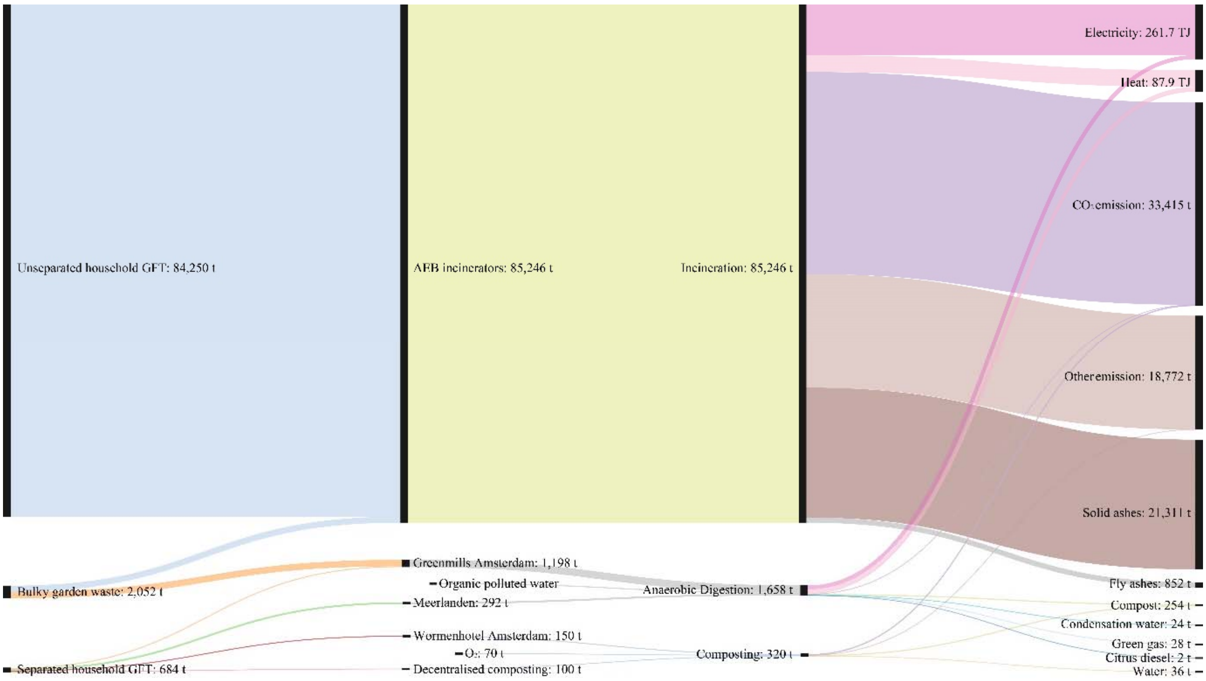

Figure 2. MFA of household organic waste flows in Amsterdam, 2019. Source: own illustration.

The Material Flow Analysis (MFA) is used to analyse the household organic waste flows at the city scale of Amsterdam in the year 2019 (Figure 2). In order to make these flows comparable, all the flows are composed of three parts: the source of organic waste, the way they are treated, and the output products of the treatment. All the relevant data are collected through literature review, government database, and reports and websites of waste processing companies. However, it is impossible to obtain accurate data on some flows like decentralised composting. Therefore, these data are mainly based on the author's own assumption. The information of detailed data and their relative sources could be found in Appendix 1.

The MFA diagram shows that nearly 97% of household organic waste is not separately collected in Amsterdam, which would make the treatment of organic waste more difficult. Then these unseparated household organic waste would end up in the incinerators of the Waste Energy Company (Afval Energie Bedrijf, AEB) with other residual waste. Through the incineration process, electricity and heat are generated for houses and business in Amsterdam. Greenmills Amsterdam and Meerlanden are two main companies that can treat organic waste in their anaerobic digesters to produce biogas and fertilisers. Only a small percentage of household organic waste is treated through composting like worm hotels in Amsterdam. There are about 200 worm hotels spreading in different communities in Amsterdam nowadays and more and more households are willing to take part in this community composting projects. Based on the information shown in the MFA diagram, we can summarise some key problems within the current household organic waste flows in Amsterdam.

Nutrients loss: Currently, most household organic waste in Amsterdam is incinerated with other residue waste. Although electricity and heat are generated in this process, most nutrients like phosphorus(P), potassium (K), and nitrogen (N) in organic waste are lost, which could be used as a potential source of fertilisers and soil improvers (Walling et al., 2010). It is also possible to separate nutrients from the remaining solid ash through washing and leaching, solidification, and thermal treatment, but this would take extra money and efforts (Zacco et al., 2014). Therefore, the incineration process is proved not to be a sustainable method of treating organic waste.

Lack of decentralisation: As is clearly demonstrated in the MFA diagram, the incineration process in AEB is the first choice of treating household organic waste. The second way is the anaerobic digestion of collected organic waste in waste processing companies such as Greenmills Amsterdam and Meerlanden. All these centralised companies rely on their garbage trucks to collect the waste at regular intervals and to transport it to their factories far away from the city. There are many problems within this centralised way of organic waste treatment. On one hand, organic waste stinks in a few days and would contaminate other recyclable waste and pose a threat to the environment and public health if not treated on time. On the other hand, the transportation cost has become a bottleneck for many waste processing companies (Lardinois, 1993). However, there are many positive developments in Amsterdam nowadays looking for decentralised ways of treating organic waste, especially at its source. Worm hotels are good examples of treating organic waste at the community level. But these only accounted for a very limited number of organic waste per year and more efforts are needed to promote decentralised treatment methods.

Lack of community involvement: The percentage of separately collected household organic waste is quite low in Amsterdam–only 4% in 2019. This is not only because the municipality of Amsterdam does not have well-developed systems for the collection of organic waste through the city, but also because most residents have not realized the importance of separating organic waste and are confused about the stream destination of organic waste (Viva et al., 2020). Nevertheless, some pilots in Amsterdam like Java Island started to collect organic waste within all the households, which appeared to be successful. At the same time, the EU ambassadors approved new rules in 2018 to ensure that organic waste is either collected separately or recycled at source by 2023 (Council EU, 2018). Therefore, this goal is far from being achieved and looks for the positive involvement of more residents in the near future.

3.2. Current organic waste treatment technologies

Many technologies have been developed to treat organic waste at different levels (from city level to neighbourhood and even building level). This research will try to get an insight into what technologies are workable at the high-rise building level. Figure 3 gives an overview of treatment technologies for household organic waste and the red ones are the current technologies being managed in Amsterdam. It is proved unsustainable if the organic waste is treated with other residual waste, for example, resources like nutrients are lost and the emissions of greenhouse gas are increased (IGES White Paper, 2008). Hence, this research will only present the main treatment technologies for separately collected organic waste with some examples and discuss their advantages and disadvantages when managed in high-rise buildings.

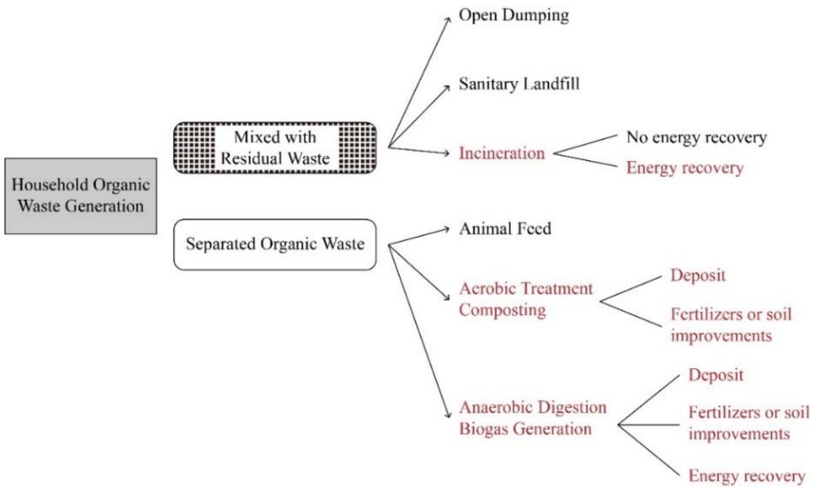

Figure 3. Organic waste treatment technologies overview. Made by author based on IGES White Paper, 2008.

3.2.1 Animal Feed:

Food waste has been used for animal feed since humans started to keep domestic animals like pigs, cattle, sheep and horses (IGES White Paper, 2008). However, feeding food waste without proper treatment will increase the risk of health problems, such as an outbreak of the foot and mouth disease in the UK in 2001. As a result, the entire EU banned the use of food waste for animal feed in 2002 (Dou et al., 2018). Currently, the protein-rich soybean imported from distant countries like Brazil is mainly used as fodder for animals in the Netherlands, producing high transportation expenses (Furlan et al., 2016).

With contemporary treatment technologies, nutritionists found that it is possible to convert food waste into safe animal feeds. In 1989, a Dutch company Nijsen/Granico started to investigate whether foodstuffs could be sustainably used as animal feeds. Now with their food-for-feed plants, they can process wasted food like bread, biscuits, pastry, and sweets into high-quality animal feed for pigs and chicken. The products are collected from different food processors or bakeries and will be transported to their plants in Veulen. Then they will be crushed in a hammer mill and their packaging can be removed mechanically. The outputs are separated raw materials. These raw materials contain about 40% dry matter and will be desiccated to 90% dry matter, which is more suitable for feed mixtures. Finally, Nijsen mixes other ingredients like fats, oils and minerals with raw materials to produce a compound feed (Uys, 2018).

The first benefit of Nijsen circular animal feed is that it can reduce the transportation cost of soybeans over long distances. This technology also uses less agricultural land and reduce greenhouse gas emissions significantly. However, this technology can only treat high-cereal food waste and has many limitations for the safety of input products. Most importantly, hygiene is of great importance when storing raw materials. Therefore, the treatment process requires high hygiene and the silos need to be observed cautiously and be cleaned regularly.

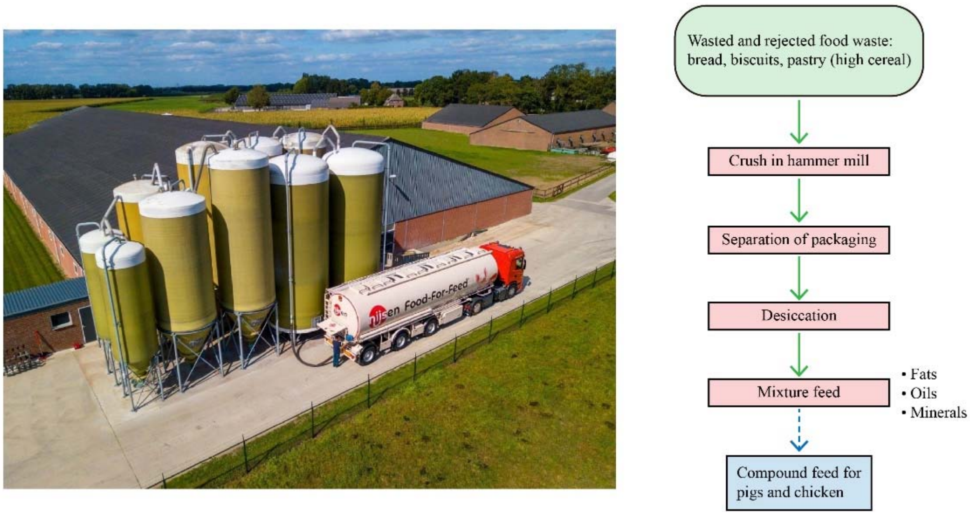

Figure 4. Animal feed: Nijsen.

Left: Nijsen food-for-feed plants. Source: https://www.tans.net/deelmarkten/productie-en-industrie

Right: Nijsen animal feed process. Source: own illustration.

Most food waste is high in protein and black soldier fly larvae (BSFL) are good sources of recovering proteins from the food waste. When larvae eat the food waste and grow into black soldier fly (BSF), they can be used as high protein fodder for pigs, chickens and fish (Furlan et al., 2016). AgriProtein in the UK is the world's leading pioneer in recycling food waste into fodder and they have their large larvae factories in Belgium and South Africa.

When the factory receives the food waste, they will first crush the food waste into small pieces and mix it with rice hull powder to create an ideal condition for the growth of BSFL. Then, larvae are added to the boxes for bioconversion. In 15-18 days, the larvae will grow into pre-pupae, which will be separated from the residue. After the separation, the residue is immature compost and will be matured through the post-composting to become mature fertilisers that can be applied in the garden. While the BSF pre-pupae will be dried in an oven at 105 °C for at least 12 hours and are high-protein animal feed (Mertenat et al., 2019). This process reduces the greenhouse gas emissions to the atmosphere significantly and provides an excellent alternative to the treatment of organic waste due to its low investments.

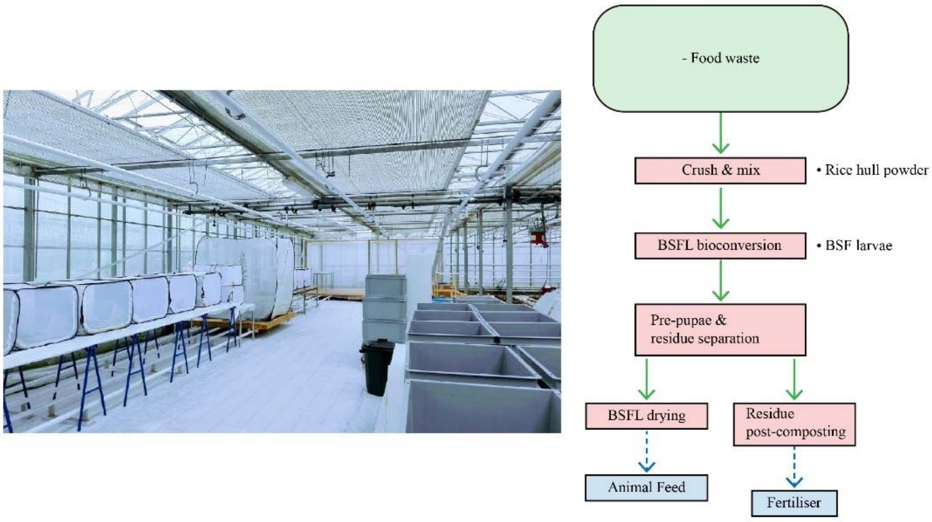

Figure 5. Animal feed: BSFL fodder.

Left: AgriProtein factory. Source: https://www.flandersinvestmentandtrade.com/invest/en/news/agriprotein-uk-acquires-insect-firm-millibeter

Right: BSFL fodder process. Source: own illustration.

3.2.2 Composting:

Composting is the aerobic decomposition of organic waste with micro-organisms under controlled conditions of oxygen, pH level, and temperature. In its simplest way, composting can be applied at the backyard by mixing kitchen waste with dry matters like woods, leaves, and papers, and turning the mixture regularly. Normally it takes about three months to finish the composting. Other composting technologies add earthworms or specialised microbes (vermicomposting) to speed up the process (IGES White Paper, 2008). The output products of composting are fertilisers with nutrients which could have positive effects on the soil structure by enhancing the soil aggregate stability and improving soil productivity (van der Wurff et al., 2016).

Currently in Amsterdam, a community composting project called the worm hotel has developed rapidly to give local residents options to separate their organic waste (figure 6). A worm hotel is a composting box on the street where local residents can compost their food scraps with the help of over 1000 tiger worms. The most suitable organic waste for worm hotels is raw vegetables and fruits, small cardboards, and also small garden waste. There are two buckets for worm families and one bottom basin for the collection of compost in a worm hotel. The worms can slide back and forth between two buckets through holes and eat the added food waste, their excrement moving in the opposite direction. As a result, the output is 100% organic high quality compost. Moreover, when the moisture content and the amount of air in the worm hotel are appropriate, the container does not emit any bad smell. Therefore, the worm hotels need more careful maintenance by the community to avoid the potential nuisance like stench, vermin and decay in the neighbourhood. The worm hotels also have positive social effects by drawing attention to circular waste flows and increasing the social cohesion in the neighbourhood. With the worm hotels, the municipality of Amsterdam will be more confident about the separation of organic waste. (Liefhebber & Tanke, 2019)

Composting could simply be applied at the household level like the backyard composting in rural areas. However, residents in high-rise areas who do not have their own backyards are also possible to treat their kitchen waste at their balcony or kitchen with simple worm compost bins (figure 7). The worm bin is odourless with the right moisture and oxygen level. Depending on the size of the bin, it can treat maximum two kilos of organic waste per day, like raw vegetables and fruits, coffee grounds, and shredded paper. The new food scraps are added to the top tray where the worms move through small holes to eat the food above. As the worms eat the scraps in the tray, they produce worm castings which will be collected in the bottom collection tray. Then the castings can be removed regularly as fertilisers for plants in the balcony or the garden (Angima et al., 2011). In short, the worm bin is a simple and clean way of treating organic waste at household level and only needs regular checks to ensure the healthy living environment of the worms.

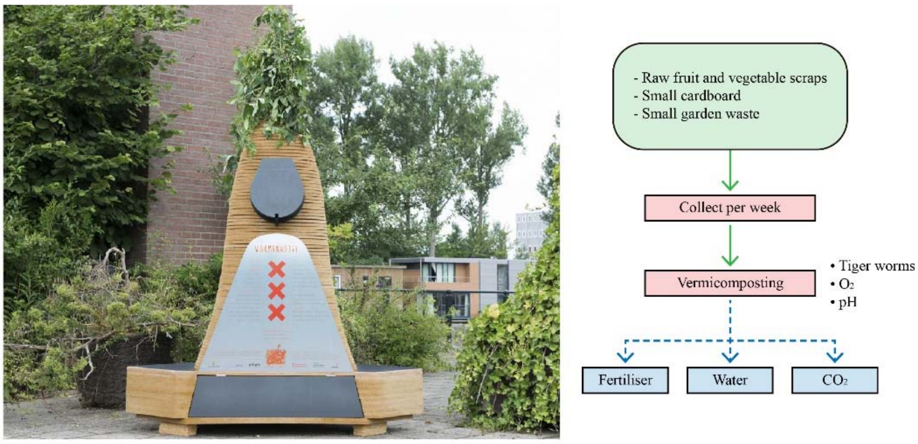

Figure 6. Composting: worm hotel.

Left: Worm hotel in Amsterdam. Source: https://www.fabfac.nl/portfolio/wormenhotels-amsterdam/

Right: Worm hotel process. Source: own illustration.

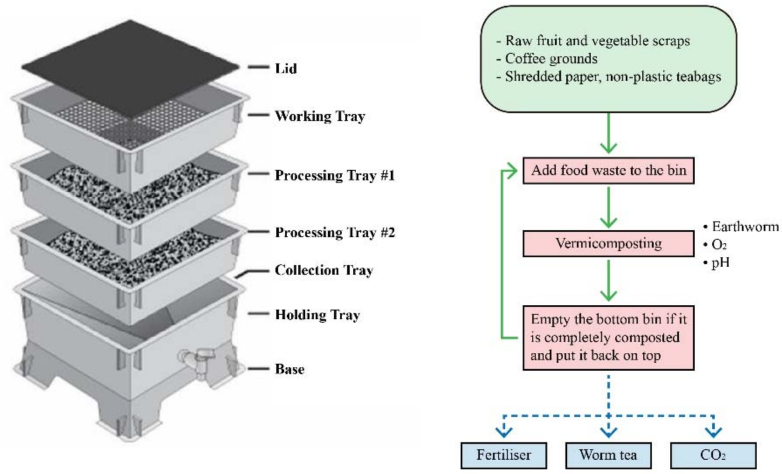

Figure 7. Composting: worm compost bin.

Left: Worm hotel in Amsterdam. Source: Furlan et al., 2016

Right: Worm compost bin process. Source: own illustration.

3.2.3 Anaerobic Digestion:

Anaerobic digestion is the decomposition process of organic waste by micro-organisms without oxygen (SANG-ARUN et al., 2011). In this process, biogas (consisting of 50%-60% methane) and digestate are generated. Biogas can be converted into electricity and heat, while the digestate with post-treatment can be used as fertilisers. Differences between wet and dry influents divide the anaerobic digestion into 'wet digestion' and 'dry digestion'. The influent of 'dry digestion' has at least 25% of dry matter, that of 'wet digestion' containing 10%-15% dry matter. The 'dry digestion' requires less water and less energy for the operation than the 'wet digestion'. But the 'wet digestion' can treat more types of organic waste including liquid kitchen waste and requires smaller reactors (Luning et al., 2003).

In the Westergasfabriek of Amsterdam, the company Waste Transformers has their anaerobic digestion installations in big containers (figure 8). Every day, they drive an electric cart to collect separated food waste from ten restaurants, one hotel and one micro-brewery in the neighbourhood. Then the collected food waste will be placed in a chopper via a chute, after which the bacteria in the digestor tank will convert the waste into biogas through four stages (figure 8). After about three weeks' processing, the generated biogas can provide 15 households with electricity and part of the heat released during the digestion process is recycled for heating the surrounding restaurants. In addition, the remaining solid substance after the process can be a fertiliser for the park. This on-site community anaerobic digestion project reduces the traffic of transporting waste to distant factories and is a small-scale sustainable alternative to the AEB Amsterdam, where organic waste goes into the incinerators (van Zoelen, 2016).

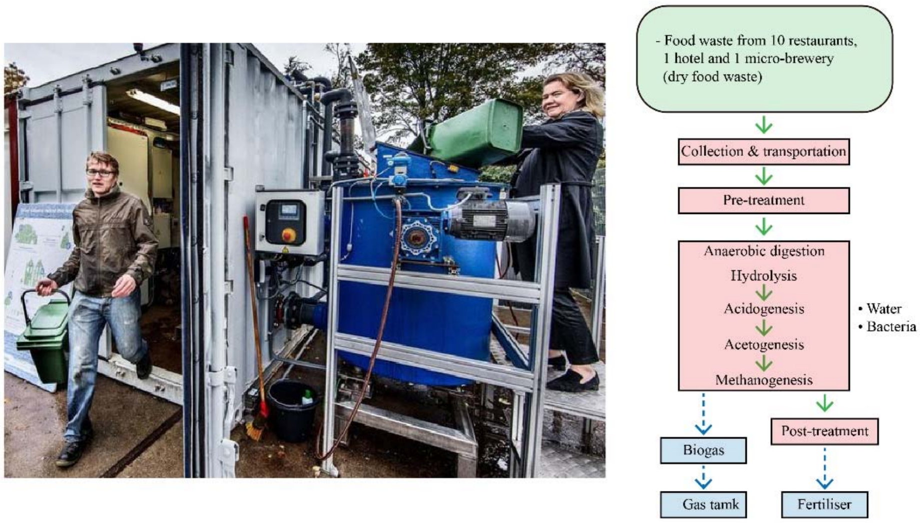

Figure 8. Anaerobic digestion: dry anaerobic digestion.
Left: Waste Transformers Amsterdam.
Source: https://www.parool.nl/nieuws/groen-gas-in-westerpark-van-etensresten-naar-stroom~b69d21a6/
Right: Waste Transformers process. Source: own illustration.

In order to solve the problem of disposing of wet kitchen waste in high-rise apartments, a wet anaerobic digestion technique is intended to collect and treat organic waste in high-rise buildings at the generation point (figure 9). Every household is equipped with a collection bin in the kitchen to collect the wet food waste. Then the collected food waste is shredded into small pieces and flushed through the pipe to the digestion tank in the basement with the help of grey water. In the tank, the waste was decomposed by the anaerobic bacteria. This process takes about one month, and the biogas will be generated and the residue waste at the bottom of the tank can be composted with earthworms to produce fertilisers (Ori, 2017). This technique was partly implemented in the Fullriggaren district in the Western Harbour of Malmo. When this area was built in 2012, sink shredders are equipped in every household of the apartment and connected to the storage tank (Bautista Angeli, 2018). Then the food waste is transported to a centralised plant outside the district instead of being treated at the source due to the capacity problem. However, this technique still has great potential to be implemented in high-rise buildings in combination with other technologies mentioned before.

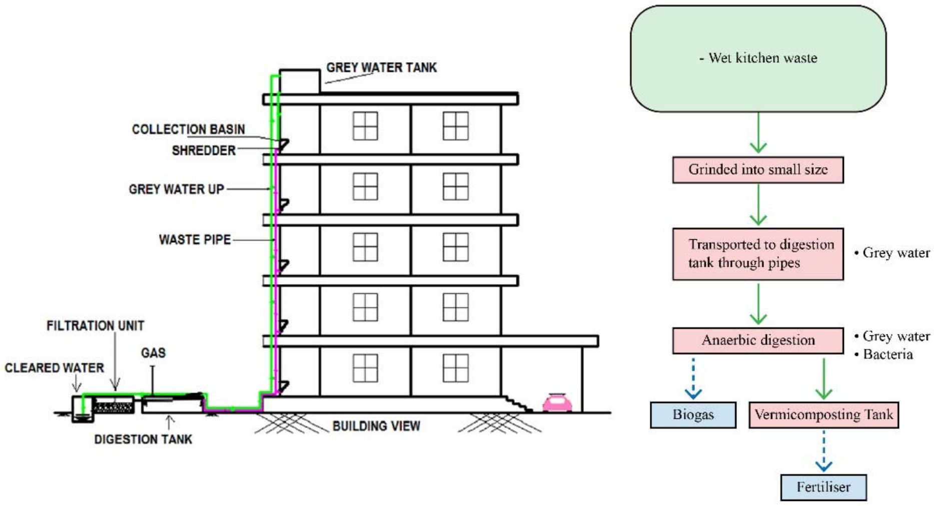

Figure 9. Anaerobic digestion: wet anaerobic digestion.
Left: General layout of a wet digestion system in an apartment. Source: Ori, 2017.
Right: Apartment wet digestion system. Source: own illustration.

3.2.4 Evaluation:

Table 1 compares the technical performance measures (TPM) of each technology described above. All these technologies are sustainable options for treating different sources of organic waste which can be collected separately at every household. And it is feasible to implement these technologies from the household scale to the community scale as decentralised alternatives to the waste incineration by AEB Amsterdam. Although the Nijsen/Granico company is collecting food waste from the city scale, we see its potential to have the decentralised plants at the community level like what the Waste Transformers in Westergasfabriek has been doing. Among all the options, anaerobic digestion can treat nearly all kinds of food waste and generate energy for the households within about one month. Composting takes the longest time than the others and does not have energy recovery, but it can produce more high-quality and safe fertilisers for the plants. More importantly, composting requires less space and can even be implemented on the balcony of the resident’s apartment. The processing boxes of BSF larvae are similar to the home composting bins in size, but the BSF larvae bioconversion process is more quickly than vermicomposting and can generate high protein fodder as well as compost.

Table 2 evaluates the sustainability impact of each case study from three aspects: economic, environmental and social aspects. Each aspect has three sub indicators that help determine the sustainability impact more precisely. As is shown in the table, decentralised composting and anaerobic digestion can significantly reduce the logistic cost of transporting organic waste. Commonly, the greenhouse gas (GHG) emissions generated by the composting are CO_2, but if the oxygen is not sufficient during the process, N_2O and CH_4 will be produced with more global warming potential than CO_2. Anaerobic digestion process collects most generated biogas with little emission into the atmosphere, but the post-treatment of digestate will generate CO_2 similar to composting. The food-to-feed process by Nijsen/Granico is environment friendly and can reduce 60% of CO_2 emissions than the traditional animal feed process. Both anaerobic digestion and animal feed technologies require energy to operate their treatment plants, while composting only needs earthworms for the treatment without energy consumption. From the social perspective, composting does not require high personnel skills and maintenance skills for the operation, so this technology is suitable for all the residents to get involved at the community level. The anaerobic digestion process is more complicated than composting and requires the operation of professionals, but it also can promote the residents’ awareness of separating organic waste properly. However, high levels of hygiene and safety are essential for the food-to-feed technology, making it less participated by local residents.

In conclusion, these organic waste treatment technologies are sustainable alternatives to the incineration process of organic waste which is widely applied in Amsterdam. Moreover, successful implementation of these technologies at the community level will speed up the progress of separating and treating organic waste at its source to achieve the circular economy. Therefore, the best solution is the combination of different treatment technologies to optimise their advantages, and this will be discussed in the next part in more detail.

TPM	Animal Feed Nijsen/Granico	Animal Feed BSFL fodder	Composting Worm hotel	Composting Worm compost bin	Anaerobic Digestion Waste Transformers	Anaerobic Digestion Wet waste digester
Input	Wasted and rejected food waste: bread, biscuits, pastry (high cereal)	Almost all kinds of food waste	Raw fruit and vegetable scraps, small cardboard, small garden waste	Raw fruit and vegetable scraps, coffee grounds, shredded paper, non-plastic tea bag	Food waste from restaurants, hotel and micro-brewery	Wet kitchen waste
Capacity	100,000 t/year	15 kg/day	2000 kg/year	Max. 2 kg/day	Max. 600 kg/day	30 kg/month
Spaces needed for treatment	25,000 m^2	1 m^2	1 m^2	0.25 m^2	50 m^2	4 m^2
Time needed for treatment	< one week	18 days	6 months	3 months	3-4 weeks	30 days
Main output	90,000 t animal feed /year	3 kg fodder /day 6 kg compost /day	ca. 1000 kg compost /year	Max. 750 kg compost /year (ca. half of food waste)	ca. 90 kg biogas /day	ca. 5 kg biogas /month

Table 1. Technical performance measures of case study. Source: own illustration.

Sustainability impact		Animal Feed Nijsen/Granico	Animal Feed BSFL fodder	Composting Worm hotel	Composting Worm compost bin	Anaerobic Digestion Waste Transformers	Anaerobic Digestion Wet waste digester
Economic	Logistic cost	High	Medium	Low	Very low	Medium	Low
	Running cost	High	Low-medium	Medium	Low	High	High
	Sales of output	Medium	Medium	Low-medium	Low-medium	Medium-high	Medium-high
Environmental	GHG emission	Low-medium (62% reduction of CO_2 compared with traditional animal feed production)	Very low	Medium (N2O & CH4 if ventilation is not enough)	Medium (N2O & CH4 if ventilation is not enough)	Low	Low
	Nutrients recovery	Medium-high	High	High	High	Medium	Medium
	Energy consumption	High	Medium	Very low	Very low	Medium	Medium-high
Social	Personnel skill	High	Medium	Low	Low-medium	Medium-high	Low-medium
	Maintenance skill	High	Medium	Low	Very low	Medium-high	Medium-high
	Community involvement	Low	Low-medium	High	Medium-high	Low-medium	Low-medium

Table 2. Sustainability impact assessment of case study. Source: own illustration.

3.3. Circular organic waste treatment scenarios in the high-rise building

3.3.1 Introduction:

In particular, the separation of organic waste is a major challenge in densely populated urban areas with many high-rise buildings due to several reasons. First, organic waste is wet, dirty and smelly and is more difficult to separate than other waste like plastic, paper and glass. Second, according to the interviews by Design Innovation Group, residents in high-rise areas who do not separate organic waste give the lack of green containers for organic waste as the main reason (Design Innovation Group, 2015). While in low-rise areas, residents usually have enough containers to collect organic waste and also can simply treat organic waste in their gardens. In Amsterdam, the average person only collected 0.6 kg of organic waste in 2019 (CBS, 2020), mainly because 86% of residents are living in apartments (CBS, 2016) and have difficulties in separating organic waste. Hence, this research aims to find sustainable solutions in high-rise buildings to separate and treat organic waste. De Knip in Sloterdijk Centre is used as a hypothetical pilot high-rise building in this research. Currently, this building is being used by Dutch tax authorities as offices, and this research hypothesizes that this building will be transformed into a high-rise residential building to meet the high demands for housing in this area in 2040.

3.3.2 Composition of Dutch household food waste:

Firstly, because different organic waste treatment technologies have different requirements for the input waste, it is essential to get insight into the composition of Dutch household food waste. The data used in this research are based on the results from a Dutch household food waste composition study by the Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs in 2016 (Appendix 2). Of course, food waste will decrease in the future. In 2018, the Task Force Circular Economy in Food organized an initiative against food waste which set a goal that food waste will reduce by half in 2030 compared to that of 2015 in the Netherlands. Therefore, this research estimates that this goal has been reached in 2040 and every resident in De Knip residential building will only generate 35-40 kg of food waste per year.

Figure 10 demonstrates the composition of Dutch household food waste, and we can see that bread is the largest part of solid food waste, which can be used for animal feed. Vegetables and fruits have a share of 11% and are suitable for vermicomposting. We also notice that leftovers from meals account for 15% as the second largest part, and the best solution to treat this type of food waste is anaerobic digestion. In addition, coffee and tea are also large sources of Dutch food waste, and their coffee grounds and tea bags are the perfect food for worms. As a result, with the basic knowledge of the amount of Dutch household food waste composition, it would be easier to promote the related solutions.

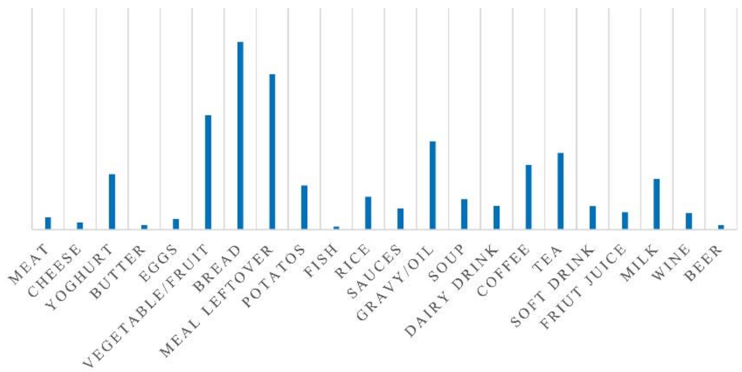

Figure 10. Dutch household food waste composition. Made by author based on van Dooren et al., 2019.

3.3.3 De Knip context:

De Knip is a 21-storey high-rise office building located on the eastern part of Sloterdijk Centre and is only 5 minutes walk from the Sloterdijk Central Station. In the redesign, the tower is planned to be transformed into dwellings for small families with no more than four family members, while the plinth will be used as commercial programs, garage, and also organic waste treatment facilities. The dwelling units per household vary from 60 m^2 to 100 m^2, depending on the size of the families. The typical floor plan of De Knip has two wings and has an area of approximately 1600 m^2. So it is assumed that each floor will have at least 10 dwelling units. To sum up, there will be 450 - 500 inhabitants living in this high-rise residential building in 2040 and they will generate approximately 16,000-20,000 kg of food waste per year. More importantly, this building will have more vertical green gardens and the garden waste is also a large amount of organic waste.

3.3.4 Case study:

There are already many practical practices of the circular organic waste treatment system in low-rise areas like the Zonneterp project in Sneek, a small town in the north of the Netherlands. However, the circular organic waste treatment system has not been realised in high-rise buildings yet and remains at the theory stage. This research will introduce two practices of on-site circular organic waste treatment system in the high-rise building. Although these practices have not been built yet, but they show the great potential to recycle organic waste as valuable resources within the high-rise building.

The first project is 'Groene Toren' in Bajes Kwartier of Amsterdam, a new vertical city park with urban agriculture renovated from a former prison tower. This building will cooperate with The Waste Transformers to use the organic waste from this building and its neighbourhood to generate green energy and produce natural compost for the open-air gardens inside and outside the 'Groene Toren'. Waste processing is currently a process that remains far from the sight of every resident. Nevertheless, with the anaerobic digestion tanks in the building (figure 11), 'Groene Toren' changes this situation and gives a public function to the tanks where visitors can touch the installations, see and experience how the organic waste is processed. The 'Groene Toren' will be a testing ground for new forms of energy generation, circular use of waste and healthy urban living.

The second project is the neighbourhood recycling centre in Hong Kong (figure 12). This project is a prototype design by Sepia Design Consultants Limited, proposing an on-site recycling solution to reduce the waste transported to landfills in Hong Kong. In the basement, there is an on-site composting centre that can treat food waste from the neighbourhood and also restaurants and food market in the building. The generated compost can be used in the organic garden on the rooftop to grow food back to the restaurants. The waste processing system is also working together with solar PV collectors and rainwater collection system contributing to the loop from waste to resources. This concept of vertically arranged facilities can be implemented in a wider variety of sites, especially in densely populated urban areas.

Figure 11. Groene Toren in Amsterdam

Source: FABRICations.

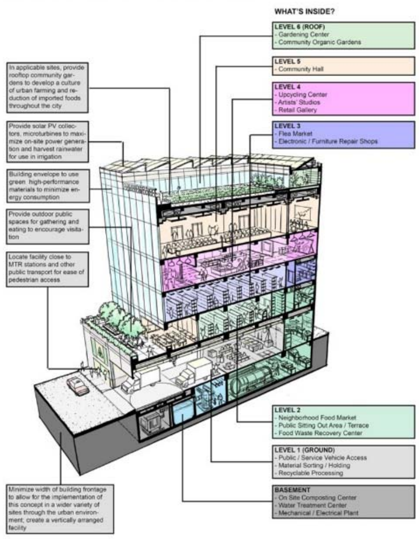

Figure 12. Community recycling centre-Hong Kong

Source: Thomas Schmidt.

3.3.5 Circular household organic waste treatment scenarios:

Figure 13-15 offer three scenarios of the circular organic waste treatment system within De Knip high-rise building based on the technologies (anaerobic digestion, composting and animal feed) and data previously mentioned. In these scenarios, the input of organic waste only includes household food waste generated by the residents. While in the redesign of De Knip, new programs like restaurants, café and vertical gardens will be added except for dwellings, which means that food waste and garden waste generated by these programs should also be considered. However, it is difficult to estimate the amount of this part of organic waste currently. Thus, to avoid complicating the scenarios, this research will set the amount of household organic waste treated by these technologies at their half capacity and focus on the household organic waste flows within De Knip.

In scenario I, wet anaerobic digestion tanks in the basement can treat liquid food waste and meal leftovers from the kitchen, and dry anaerobic digestion containers implemented in the building's plinth can process dry food waste like vegetables, fruits, bread, and other solid food waste. This scenario has already been proposed in the project of 'Groene Toren'. During this process, approximately 2160 m^3 biogas in total will be produced per year for the electricity and heating of this building. The residue waste after the anaerobic digestion process is composted again, producing about 6800 kg fertilisers for gardens.

Composting technologies are added to the scenario II to promote the participation of the residents. Raw vegetables and fruits, coffee grounds and tea bags can be treated either in the community worm hotels or at home worm composting bins. Stale bread without other ingredients like dairy can also be added to compost with vegetables and fruits. This process can generate more high-quality fertilisers but emitting more carbon dioxide into the atmosphere. The rest of the food waste that is not suitable for composting will be transported to the anaerobic digestion tanks. This scenario appeals to all the residents to take the active participation in separating and treating organic waste at the source.

Scenario III implements all three types of technologies in the building. The stable bread can be collected to food-to-feed plants to produce high-cereal fodders, and meal leftovers can be treated by BSFL bioconversion to produce high-protein fodders. It is estimated that around 1170 kg of fodders will be generated per year for chickens or pigs in urban farming. The animal feed process requires higher hygiene to guarantee the safety of the fodders. Meanwhile, anaerobic digestion and on-site composting generate approximately 6940 kg of compost and 1410 m^3 of biogas per year. This scenario provides more diverse options to treat organic waste, hence requiring the residents to separate the organic waste more cautiously. Most importantly, this scenario reduces the CO_2 emissions significantly digestion as compared to scenario II as both animal feed technologies emit less CO_2 than composting and anaerobic.

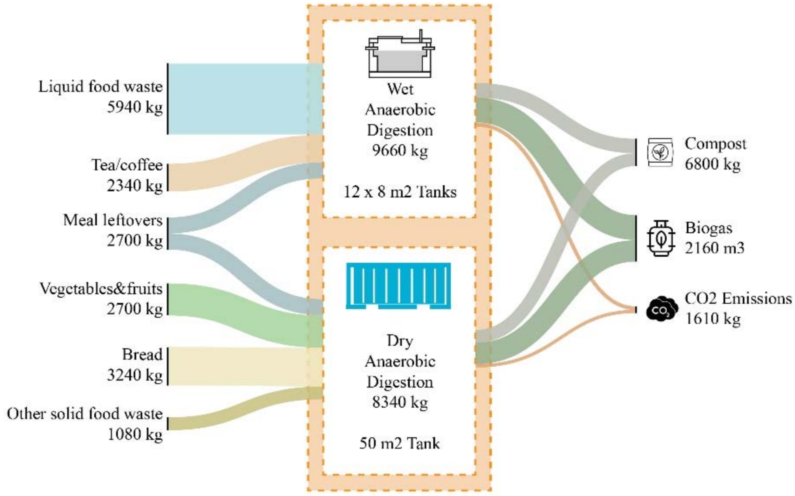

Figure 13. Scenario I (AD). Source: own illustration.

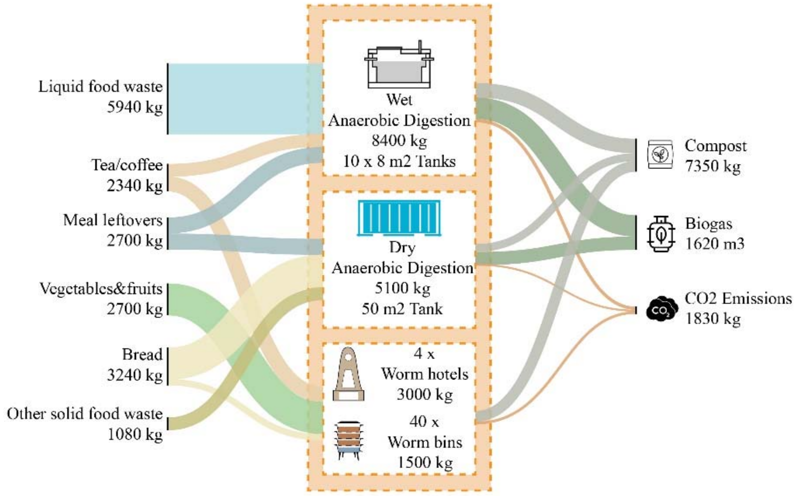

Figure 14. Scenario II (AD + Compost). Source: own illustration.

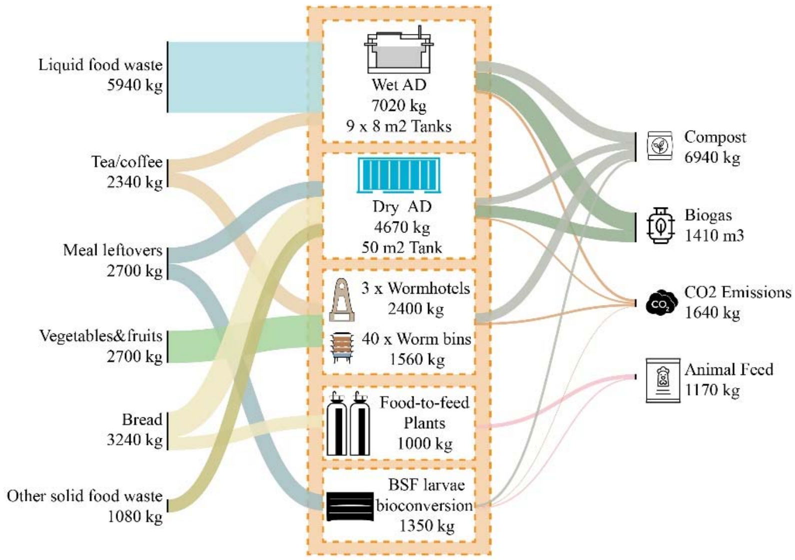

Figure 15. Scenario III (AD + Compost + AF). Source: own illustration.

3.3.6 Evaluation:

These three circular organic waste flow scenarios are all sustainable and applicable options to reuse organic waste as resources at the source. The above sustainability impact assessment matrix (Table 2) has already built the evaluation framework for each technology from economic, environmental and social aspects, and thus can also be applied to evaluate these three scenarios. To make these scenarios comparable, this research scores each technology's sustainability impact from nine indicators (Appendix 3). The scores are mainly based on the comparison between each technology's technical performance measures and the knowledge from the existing literature (IGES White Paper, 2008, Lardinois, 1993, Luning, 2003, SANG-ARUN et al., 2011). However, these scores do not present the absolute values of each technology, and can only reflect each technology's relative sustainability performance. Therefore, according to this scoring matrix, every scenario with a different percentage of treatment technologies (animal feed, composting and anaerobic digestion) can have a preliminary assessment with a grade on each sustainability aspect.

Figure 16 visualises the sustainability performance of three scenarios with a radar chart. It is clear that scenario I is inadequate in social sustainability. In other words, most residents cannot engage positively in scenario I due to the anaerobic digestion's high requirement for personnel and maintenance skills. Additionally, scenario I has the lowest scores on the environmental sustainability aspect because of the high energy demand for the operation of anaerobic digestion plants. Therefore, scenario I is not the most sustainable solution. Scenario II gets the highest scores in terms of economic and social sustainability because anaerobic digestion generates biogas as renewable energy for household applications and community composting can promote the active participation of all the residents. Similarly, scenario III performs as well as scenario II regarding economic and social sustainability. However, scenario III is the most environmentally friendly solution because both Nijsen's food-to-feed technology and BSF larvae bioconversion can reduce greenhouse gas emissions significantly. To sum up, scenario III has a balance on three sustainability aspects and offers more diversity to treat organic waste. Consequently, this research assumes that scenario III is the most sustainable and applicable solution to use organic waste as resources at its point of generation within De Knip high-rise residential building.

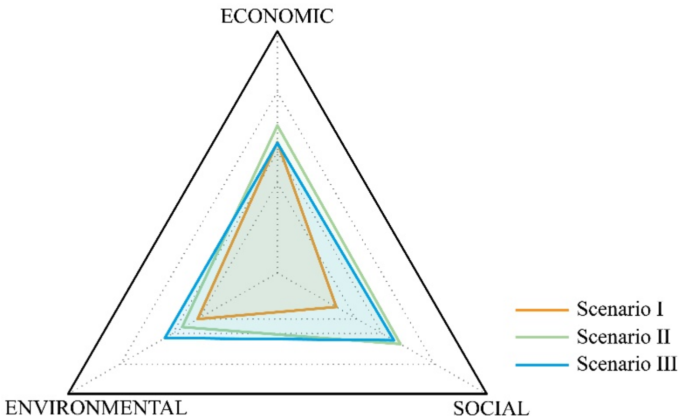

Figure 16. Preliminary assessment of scenarios. Source: own illustration.

3.3.7 Discussion:

Since the most preferred solution is the combination of composting, anaerobic digestion and animal feed, this circular system will be applied in the renovation process of De Knip. Accordingly, this research will propose some brief design principles regarding the implementation of this circular system within the existing high-rise building.

Program scenarios

De Knip will be renovated from an office tower to a dwelling tower with organic waste treatment facilities added. More vertical gardens and roof farming can be added to the existing building so that the fertilisers generated from composting can be used to grow plants in the gardens. Moreover, the poultry farming like keeping chickens is also feasible at the roof the building's plinth and the organic waste treatment system can provide high cereal and protein fodders for chickens. Then chickens can provide eggs and meat for the households and restaurants. As a result, the synergetic management between different programs contributes to the dynamic living environment of residents.

Location

The organic waste treatment facilities like anaerobic digestion tanks are suitable to be placed in the plinth of the high-rise building, and are preferred to be near the sub-entrance, so they can also treat organic waste collected from the surrounding neighbourhoods. Worm hotels can be placed in communal gardens with convenient access by all the residents, while the north balconies of the households are suitable for worm composting bins.

Visibility

Currently, the waste processing is always far from residents' sight because most waste is transported to the centralised factories isolated from the urban context. As a result, most people do not know where the waste they produced has gone and how it will be processed. Therefore, this decentralised organic waste treatment system has the potential to display the process of the organic waste treatment, from collection, to treatment and the end products. This system should be designed visible for all the residents to raise people's awareness of separating organic waste in the high-rise building.

Connection with other systems

This organic waste treatment system also has a synergetic relationship with other building systems. For example, the rainwater collection system can work together with the wet anaerobic digestion process to flush the food waste from the kitchen to the digestion tanks. The biogas generated from the anaerobic digestion can provide heat and electricity for the households. And the roof farming and poultry farming can provide extra food system for the whole community.

IV. CONCLUSIONS

This research explores the possibility of implementing a decentralised and circular household organic waste treatment system within a high-rise residential building in Amsterdam. This decentralised organic waste treatment system aims to recycle organic waste as valuable raw materials and acts as a sustainable alternative to the current centralised incineration processing of most organic waste in AEB plants. And the proposed scenarios prove that it is applicable to treat the household organic waste generated by the residents at the source by composting, anaerobic digestion and animal feed. The most preferred solution can produce 1410 m^3 biogas, 6940 kg compost and 1170 kg animal feed for the community per year. Furthermore, the residents will have more chances to work together with their neighbours on treating the organic waste from their kitchen. This would enhance community cohesion, which is often missing especially in high-rise buildings. As a result, the proposed organic waste treatment system can serve as a pilot project of separating and treating organic waste within high-rise buildings in densely populated cities.

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APPENDIX

1. Amsterdam organic waste flow data

Household organic waste input			
	Year	Data	Source
Household residual waste	2019	238.4 kg/p	CBS
Total household residual waste	2019	271,776 t	
Share of organic waste in household residual waste	2019	31%	MIE
Total household organic waste	2019	84,250 t	
Household organic waste separately collected	2019	0.6 kg/p	CBS
Total household organic waste separately collected	2019	684 t	
Bulky garden waste	2019	1.8 kg/p	CBS
Total bulky garden waste	2019	2052 t	
Total household organic waste	2019	89,986 t	

Household organic waste treatment				Output product			
		Amount of GFT / year	Source	Raw materials	Proportion (output/input)	Amount	Source
Incineration	AEB	85,246 t	Amsterdam Municipality	Electricity	850 kWh/t	260 TJ	AEB website
				Heat	280 kWh/t	86 TJ	
				Solid ashes	250 kg/t	21311 t	De Waart, 2009
				CO_2	390 kg/t	33246 t	
				Fly ashes	10 kg/t	852 t	
				Other emissions	220 kg/t	18754 t	
Anaerobic Digestion	Greenmills Amsterdam	1198 t	Greenmills website	Compost	29 kg/t	35 t	Greenmills website
	Organic polluted water	168 t		Electricity		1.7 TJ	
				Heat		1.7 TJ	
	Meerladen	292 t	Meerladen website	Compost	360 kg/t	105 t	Meerlanden website
				Green gas	47 m^3/t	13724 m^3	
				CO_2	57.6 kg/t	17 t	
				Citrus diesel	0.22 L/t	64 L	
				Heat	182 kWh/t	0.2 TJ	
				Water	82 kg/t	24 t	
Composting	Worm hotel Amsterdam (currently 75 in Amsterdam)	150 t	Worm hotel website	CO_2	0.69	103 t	Angima et al., 2011 Nigussie et al., 2016
				Compost	0.54	81 t	
	O_2	70 t		Water	0.24	36 t	
	Decentralised composting	100 t	Assumption	CO_2	0.49	49 t	Viva et al., 2020
				Compost	0.33	33 t	
				Other emissions	0.18	18 t	

2. Dutch household food waste composition 2016 (Source: van Dooren, 2019)

Food waste	Amount of waste per person /kg	Percentage wasted per person
Meat	1.19	1.2%
Cheese	0.66	0.7%
Yoghurt	5.22	5.3%
Butter	0.43	0.4%
Eggs	0.99	1.0%
Vegetables/fruits	10.76	10.9%
Bread	17.71	18.0%
Meal leftovers	14.66	14.9%
Potato	4.16	4.2%
Fish	0.29	0.3%
Rice	3.10	3.1%
Sauces	2.01	2.0%
Gravy/oil	8.32	8.5%
Soup	2.86	2.9%
Dairy drink	2.25	2.3%
Coffee	6.11	6.2%
Tea	7.20	7.3%
Soft drink	2.19	2.2%
Fruit juice	1.63	1.7%
Milk	4.77	4.8%
Wine	1.54	1.6%
Beer	0.44	0.4%
Total	98.5	100%

3. Sustainability impact scores of organic waste treatment technologies

Sustainability impact		Animal Feed Nijsen/Granico	Animal Feed BSFL fodder	Composting Worm hotel	Composting Worm compost bin	Anaerobic Digestion Waste Transformers	Anaerobic Digestion Wet waste digester
Economic	Logistic cost	25	50	75	100	50	75
	Running cost	25	50	75	100	25	50
	Sales of output	75	75	50	50	100	100
	Average	41.7	58.3	66.7	83.3	58.3	75
Environmental	GHG emission	75	100	50	50	75	75
	Nutrients recovery	100	100	75	75	50	50
	Energy consumption	25	75	100	100	75	50
	Average	66.7	91.6	75	75	66.7	58.3
Social	Personnel skill	25	75	100	100	50	75
	Maintenance skill	50	75	75	100	50	50
	Community involvement	50	75	100	100	50	75
	Average	41.7	75	91.7	100	50	66.7

4. Sustainability impact scores of scenarios

Sustainability impact scores			Economic	Environmental	Social
Scenario I	Food-to-feed	0%	41.7	66.7	41.7
	BSFL fodder	0%	58.3	91.6	75
	Worm hotel	0%	66.7	75	91.7
	Worm compost bin	0%	83.3	75	100
	Dry anaerobic digestion	46.3%	58.3	66.7	50
	Wet anaerobic digestion	53.7%	75	58.3	66.7
	Total	100%	67.3	62.2	59.0
Scenario II	Food-to-feed	0%	41.7	66.7	41.7
	BSFL fodder	0%	58.3	91.6	75
	Worm hotel	16.7%	66.7	75	91.7
	Worm compost bin	8.3%	83.3	75	100
	Dry anaerobic digestion	28.5%	58.3	66.7	50
	Wet anaerobic digestion	46.5%	75	58.3	66.7
	Total	100%	69.5	64.9	68.8
Scenario III	Food-to-feed	5.6%	41.7	66.7	41.7
	BSFL fodder	7.5%	58.3	91.6	75
	Worm hotel	13.3%	66.7	75	91.7
	Worm compost bin	8.7%	83.3	75	100
	Dry anaerobic digestion	25.9%	58.3	66.7	50
	Wet anaerobic digestion	39%	75	58.3	66.7
	Total	100%	67.2	67.2	67.8