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Authors' foreword

This project has been a cooperation between the Solid Waste Department at VA SYD and the Water and Environmental Engineering at the Department of Chemical Engineering at Lund University.

VA SYD is a regional wastewater organization operating in Southwest Skåne and also handles solid waste in the municipalities of Burlöv and Malmö. VA SYD is a local authority, which means that it is a politically driven organization made up of member municipalities. Member municipalities are Burlöv, Eslov, Lund and Malmö.

Water and Environmental Engineering at Lund University planned and performed the sampling together with VA SYD and has been responsible for the chemical analyses and the biogas potential tests.

A reference group has been tied to the project, consisting of:
Tobias Persson, SGC (project coordinator)
Gabriella Eliasson, Trelleborgs kommun
Jonas Dahllöf, Stockholm vatten
Marinette Hagman, NSVA
Jonas Hed, Kretslopp och vatten, Göteborg stad
Maria Lööf, Miljöförvaltningen, Malmö stad
Christian Röder, Fastighetskontoret, Malmö stad

Summary

The food waste disposer (FWD) system at Fullriggaren in Malmö was evaluated over two years. The project:

- investigated the source-separation ratio of food waste through waste composition analyses
- compared different methods for sample collection from separation tanks
- determined the potential biogas production in grinded food waste through batch test methods
- analyzed content of organic matter and limiting components in the grinded food waste
- analyzed outlet samples to calculate losses of food waste from the separation tank
- calculated carbon footprint from FWD-system compared to conventional collection system via system analysis

33-55% of the food waste is collected in the tank. Since the waste is already pre-treated there will be no losses after the collection. The rest of the food waste is either found in the residual waste (37%) or passes the tank and goes with the outlet to the sewer (23-33%). It should be noted that the sum of dry matter in the tank, outlet and residual waste is higher than the expected food waste into the system. The difference is partly explained by the ordinary kitchen sewage like food scraps, drinks, sauce etc. The relatively high dry matter content (3-5%) indicates that the separation tanks are able to thicken the waste substantially. The methane potential tests also showed that there is high methane potential.

The quality of the outlet is indicating a satisfactory separation of particulate organic matter and fat. A portion of the organic content and nutrients from the waste or the kitchen wastewater is in dissolved form and cannot be caught in the tank but is led to the sewage via the outlet. No indications of elevated silver concentrations in either tank content or outlet water were seen although the grinders include a bioshield layer, which could lead to silver release.

Three methods for taking samples from the tank were compared. The Winckler method was considered most appropriate for this project since it is simple, it does not demand a vacuum truck, samples can be taken out for evaluation of the development between two emptying periods and it gives information about the function of each compartment.

When comparing the two different tank systems installed some differences can be seen. The Eastern system, with a larger separation tank, has a higher DM/household and week and also higher methane potential/VS. This indicates that the Eastern system is more effective from a biogas production perspective, however more tests are needed to verify this.

An environmental assessment of the FWD-system shows that this system can be preferable in relation to emissions of greenhouse gases, compared to a reference system with separate collection of household food waste in paper bags. The main reasons for this are a higher substitution of diesel and mineral nitrogen fertilizer in the

FWD-system. However, decreased losses of organic matter in mechanical pre-treatment of food waste collected in paper bags or decreased substitution of mineral nitrogen fertilizers with high environmental impacts in the FWD-system, could make compared systems equivalent in relation to GHG-emissions, or even change the hierarchy. Thus, relatively small changes in values affecting methane production and nutrient recovery can have impacts on results that would alter overall conclusions from the carbon footprint study. This should be held in mind in the interpretation of results gained in the study.

Sammanfattning på svenska

Insamling av matavfall från hushåll för biogasproduktion blir allt vanligare i Sverige. Insamlingen sker idag främst med papperspåse, men även insamling i plastpåse förekommer (Avfall Sverige, 2013). I flera andra länder är dock nermalning av matavfall med kökskvarnar ett vanligt sätt för separat hantering av matavfall från hushåll. I Malmö testades ett system med kökskvarnar i hushåll kopplad till uppsamlingstank för första gången i samband med Bo01, i början av 2000-talet. Ett liknande system installerades 2007, kopplat till drygt 140 lägenheter i Turning Torso i Malmö. Systemen har utvärderats i flera omgångar från olika perspektiv. Utvärderingarna visade på förbättringspotentialer i utformningen av systemen och låg till grund för ett system som installerades i kvarteret Fullriggaren i Malmö 2012. I Fullriggaren har 16 fastighetsägare i samarbete med VA SYD installerat kvarnar i 614 lägenheter, och kopplat dessa till två separata uppsamlingstankar (västra respektive östra systemet). Installationen har utvärderats under två år utifrån följande syften:

- undersöka eventuella skillnader i källsorteringsbeteende mellan områden med olika system för matavfallshantering genom plockanalyser
- jämföra olika metoder för provinsamling från de avskiljningstankar som kvarnarna kopplats till
- fastställa den potentiella biogasproduktionen i malt matavfall genom satsvisa rötförsök
- analysera halten av organiskt material och begränsande komponenter i det malda matavfallet
- analysera prover från avskiljningstankarnas utlopp för att beräkna förluster av matavfall till avloppsnätet
- beräkna klimatpåverkan från kvarnsystemet jämfört med ett konventionellt insamlingssystem via systemanalys

Plockanalyser av restavfall från hushållen i Fullriggaren genomfördes i september 2013 och september 2014. Dessutom genomfördes plockanalyser av restavfall i ett närliggande kvarter där matavfall källsorteras i papperspåsar. Resultaten visar att både mängd och sammansättning i det matavfall som inte sorteras av hushållen är mycket likartad i de båda områdena. Detta tyder på att hushållens källsorteringsbeteende inte påverkas i någon större utsträckning av valet av system för källsortering av matavfall. Ytterligare och upprepade plockanalyser krävs dock för att fastslå detta.

Intervjuer som genomfördes med sex av hushållen i Fullriggaren visar på en ökande tillvänjning av kökskvarnen och endast i ett fåtal fall upplevdes systemet orsaka problem genom skakande diskbänkar, oljud eller igensättningar i köksavloppet. Hushållen upplevde ofta att de med tiden lärde sig hur kvarnen ska hanteras för att minimera problem och maximera komfort.

Tre metoder för provtagning av nedmalt material från avskiljningstankarna undersöktes. Den sk Winckler-metoden ansågs lämpligast för detta projekt, eftersom den är enkel, inte kräver användning av sugbil, medger att prover tas ut för utvärdering mellan två tömningstillfällen och ger information om funktionen för varje fack i tanken.

Resultaten från den tekniska utvärderingen visar att 33-55% av matavfallet som genereras av hushållen samlas i tankarna. Eftersom avfallet inte kräver någon ytterligare förbehandling, uppstår inga övriga förluster av material efter hämtningen. Resten av matavfallet återfinns antingen i restavfallet (37%) eller passerar tanken och går med utloppet till avloppet (23-33%). Det bör påpekas att summan av torrsubstansmängderna i tanken, i utloppet och i restavfallet blev högre än den förväntade mängden in till systemet (som beräknats genom att titta på mängden matavfall i restavfallsfraktionen och mängden matavfall som sorteras ut i grannområdet med papperspåsar). Skillnaden beror till viss del på att det tillförs matavfall genom köksavloppet i form av matavskrap från tallrikar, sås, dryck etc. Denna mängd uppkommer och hamnar i avloppet oavsett om köksavfallskvarnar används eller ej.

Den relativt höga torrsubstanshalten i material som samlats upp från tanken (3-5%) indikerar att avskiljningstankarna kan förtjocka avfall betydligt.

Det organiska innehållet i avfallet som samlas in i tankarna är högt, ca 95 % av torrsubstanshalten, vilket antyder att potentialen för biogasproduktion är hög. Biogaspotentialtesten visade också att avfallet har en hög metanpotential. Nästan 90% av den teoretiska potentialen uppnåddes för det östra systemet och 78% för det västra systemet. Mer än 90% av gasen produceras under försökets 11 första dygn, vilket tyder på en snabb nedbrytning.

Vid en jämförelse mellan de båda tankesystemen, dvs det östra och det västra kan vissa skillnader identifieras. Det östra systemet, med en stor avskiljningstank, samlar in mer organiskt avfall/hushåll och vecka och har även högre metanpotential/VS. Detta tyder på att det östra systemet är mer effektivt, sätt ur ett biogasproduktionsperspektiv. Ytterligare forskning krävs dock för att fastställa detta.

Elementaranalysen visade att avfallet som samlas i tankarna har lågt metallinnehåll, men för några prover låg koppar och zinkkoncentrationerna över gränsvärdet för återanvändning som näring på åkermark. Kadmiuminnehållet var lågt och under de nuvarande gränsvärdena för slam eller rötrest till åkermark. Kvoten mellan kadmium och fosfor ligger mellan 30-47 mg Cd/kg P, vilket är på gränsen eller något högre än REVAQ-systemets gräns för avloppsslam. Det relativt höga värdet på denna kvot beror på att matavfall generellt innehåller lite fosfor. Kvarnavfallets Cd/P-kvot är dock inte högre än i matavfall som sorterats ut på annat sätt.

Kvaliteten i utloppet indikerar en tillfredsställande separation av partikulärt organiskt material och fett. En del av det organiska innehållet och näringsämnena från avfallet eller köksavloppsvattnet är dock i löst form, och kan inte fångas i tanken, utan leds via utloppet till avloppsnätet och hamnar slutligen i avloppsreningsverket. Genomförda analyser visar inte på några indikationer på förhöjda silverhalter i varken tankinnehåll eller i utgående vatten. Detta trots att de kökskvarnar som installerats i Fullriggaren innehåller ett så kallat bioshield-skikt, innehållandes silverjoner.

Analys av klimatpåverkan från kvarnsystemet och ett referenssystem med separat insamling av hushållens matavfall i papperspåsar har gjorts. Denna visar att kvarnsystemet kan vara att föredra. De främsta skälen till detta är förluster av organiskt material i den mekaniska förbehandlingen av matavfall som samlats in i papperspåsar, samt en högre ersättning av mineralkvävegödsel i kvarnsystemet jämfört med referenssystemet. Klimatpåverkan från transporter är låg i båda jämförda alternativen, eftersom biogas i båda fallen används som bränsle, och eftersom insamling i referenssystemet antas ske med tvåfacksbil, vilket gör att endast 15 % av bränsleförbrukningen vid insamling allokeras till matavfall. De processer som ger störst bidrag till klimatpåverkan är i båda fallen relaterade till metanemissioner från rötningsanläggning och uppgradering av biogas, dvs. processer som inte skiljer sig åt mellan de system som jämförts, utöver det faktum att ju mer metan som produceras från insamlat matavfall, desto högre emissioner.

Att mängden gödsel som ersätts är större i kvarnsystemet beror i hög utsträckning på att en hel del organiskt material som normalt sett spolas ut i köksavlopp och leds direkt till avloppsreningsverket samlas i kvarnsystemet upp och transporteras till en biogasanläggning. Känslighetsanalyser visar att minskade förluster av organiskt material i den mekaniska förbehandlingen av matavfall som samlas in i papperspåsar kan göra påssystemet mer fördelaktigt ur klimatsynpunkt, jämfört med kvarnsystemet. Detsamma gäller en situation där klimatpåverkan från produktion av mineralkvävegödsel minskar kraftigt, eftersom detta har en stor betydelse för de positiva miljöeffekter som kan kopplas till kvarnsystemet.

Resultaten från en energibalans, genomförd på primärenergibasis, visar dock att referenssystemet är mer fördelaktig. Även för energibalansen överskuggas processerna i insamlingsledet av energianvändningen i rötning och uppgradering, med undantag för elförbrukning i kökskvarnar, som ger ett relativt högt bidrag till primärenergianvändningen från detta system.

Nämnas bör att eventuell påverkan på processer nedströms i avloppssystem och reningsverk från kvarnsystemet inte inkluderats i denna analys. Detta är ett område för vidare studier för att ytterligare förbättra bilden av denna typ av källsortering ur ett systemperspektiv.

Contents

Terminology and abbreviations

Biochemical methane potential (BMP) – Biokemisk metanpotential

Dry matter (DM) – Torrsubstans

Chemical oxygen demand (COD) – Kemisk syreförbrukning

Food waste disposer (FWD) – Köksavfallskvarn

Food waste sludge – Kvarnat matavfall som samlas upp från uppsamlingstank

Greenhouse gases (GHG) – Växthusgaser

Ground food waste – Kvarnat/Nermalt matavfall

Kitchen sink – Köksvask/Diskho

Lifecycle assessment (LCA) – Livscykelanalys

Pre-settler - Försedimentering

Residual waste - Restavfall

Reference system (RS) - Referenssystem

Separation tank – Avskiljningstank

Source-separation ratio - Källsorteringsgrad

Suspended solids (SS) – Suspenderat material

Tank compartment – Tankens olika fack/sektioner

Vacuum truck - Slamsugbil

Volatile fatty acids (VFA) – Flyktiga fettsyror

Volatile solids (VS) – Glödförlust

Waste composition analysis – Plockanalys

Wastewater treatment plant (WWTP) – Avloppsreningsverk

1. Background

Food waste separation can be found in most Swedish municipalities. Waste bin and some kind of bag is the most common system (Avfall Sverige, 2011). As separation is introduced in more and more municipalities, the interest for alternative collection systems increases.

The increased interest is due to:

- Lack of space. Can be hard to make room for more bins in recycling room in for example old town centers (Morfeldt, 2013).
- Hygiene and comfort. Handling of food waste is sometime perceived as unhygienic by the users (Ewert et al, 2009).
- Aim to increase the separation of food waste.Getting the household to separate a larger fraction of generated food waste has been identified as a bottleneck for increased biogasproduction from household waste. The other bottleneck is to reduce losses of biodegradable material in the mechanical pre-treatment step necessary when food waste is collected in bags (Bernstad Saraiva Schott, 2012).
- Limiting of heavy goods in dense areas. In the denser city it becomes more difficult to reach every bulding with large vehicles for waste collection. More waste fractions calls for either more transports or larger vehicles. (Morfeldt, 2013).

One of the techniques that has received much attention in recent years is waste disposers. Waste disposers that grind food waste and send it out on the sewerage system has long existed in the USA. Projects have been made in some Swedish municipalities, mainly Surahammar (Evans et al, 2010) and Staffanstorp (Nilsson et al, 1990), but waste disposers received proper attention as the City of Stockholm in 2008 allowed usage of waste disposers in private households (Stockholm Vatten, 2013).

In the city of Malmö it is not allowed to connect disposer directly to the sewerage system. The reason is, according to VA SYD, that the sewer system has a very small slope because of the flat landscape. This impedes the transportation of waste drains. Although the grid would be able to transport the food waste to sewage treatment plants the treatment would be more difficult and expensive; more electricity and chemicals would have to be used (VA SYD, 2014).

In Malmö, an alternative system is under evaluation. A system in which the assumed benefits of the disposer are kept, for example user friendliness and space saving. But instead of flushing down the food waste into the drain and mix it with sewage the ground food waste is collected into a tank. The tank is emptied with a traditional sludge collection truck and the food waste can then be delivered directly into the biogas plant. The system of waste disposers to sepration tank in apartment blocks is unique to Malmö and has previously only been tested in small pilot projects.

The previous pilot projects were done in two properties in housing exhibition of Bo01 (41 apartments) and the Turning Torso (147 apartments). None of these projects has been considered sufficient to make a meaningful evaluation of the system. A full-scale project has therefore been carried out between October 2012 and October 2014 in the neighborhood Fullriggaren in the Western Harbor.

1.1 The waste disposer system in Fullriggaren

Fullriggaren is located in the Western harbor in Malmö and has 614 apartments spread over 16 properties. When the area was built, in 2012, disposers were installed in all apartments. The disposer is mounted directly in the ordinary kitchen sink. The houses were built with double drain strains, one from the bathroom that goes to the regular wastewater and one from the kitchen led to the separation tank. A pump inside each property presses the kitchen drain to the separation tank. Pump and pressure lines can be comparable to the LTA system used in sewers. The main difference with the LTA is that the pump in Fullriggaren does not have any cutting parts. These have been removed because if the food waste is ground once again it does not sediment properly and risks to flow through the collector tank. The sludge in the tank is emptied by a traditional sludge collection truck and transported to the biogas plant. System description is shown in Figure 1 (Bernstad Saraiva Schott, 2012).

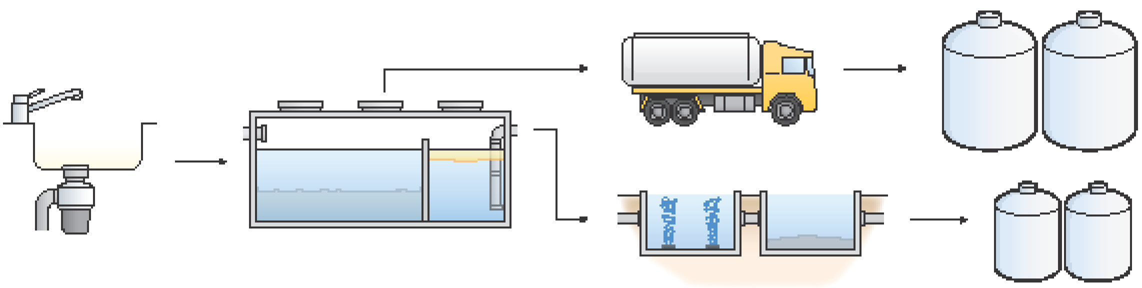


Figure 1. System description of waste disposer connected to separation *tank).*

The separation tank is divided into two compartments. The first, larger one allows the grinded food waste to settle to the bottom of the tank. The other compartment traps the sludge and grease floating on the surface. Excess water then flows out to the ordinary sewerage.

The area was divided into two parts due to the large number of apartments, see Figure 2.

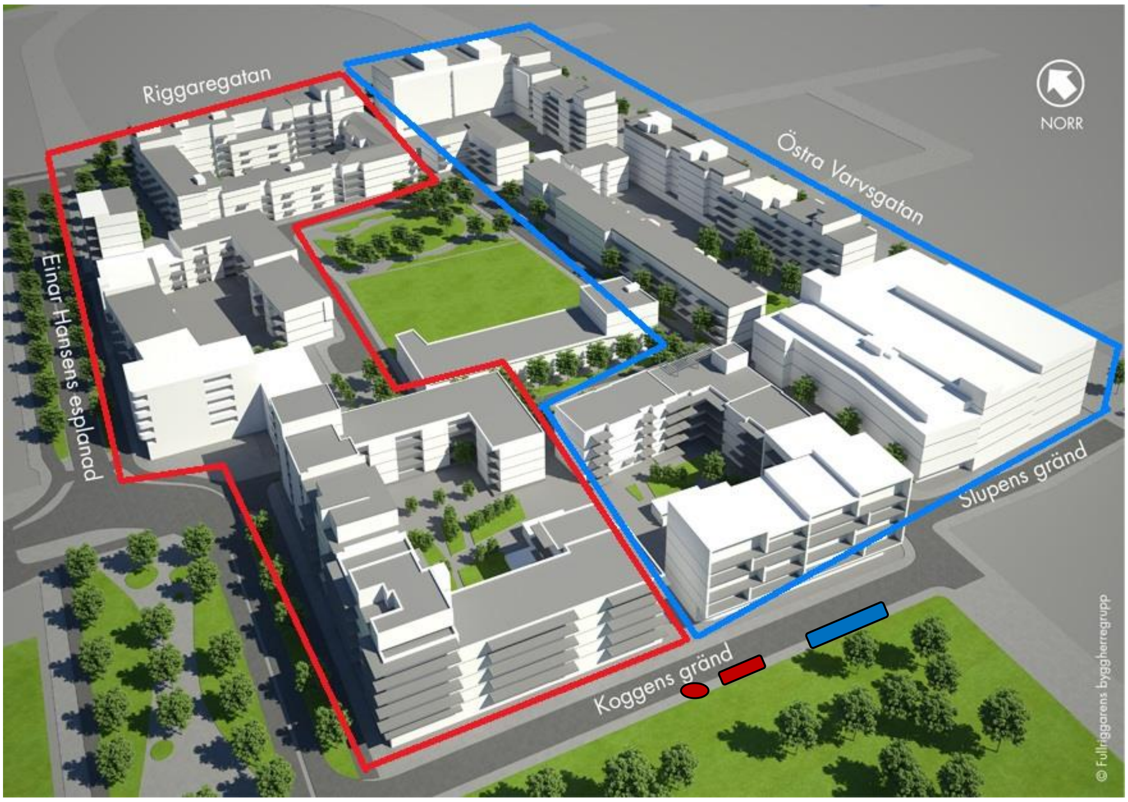


Figure 2. Illustration of the area of Fullriggaren with the separation *tanks, Western (red) and Eastern (blue).*

The eastern part was connected to a tank as described above. The western part is connected to a smaller tank that was supplemented with a so-called pre-settler, a cylindrical concrete tank. The purpose of installing two different types was to see which collection system that had the best function. The tanks including its compartments are shown in Figure 3. The sampling points have been named East tank 1-4 and West tank 1-4.

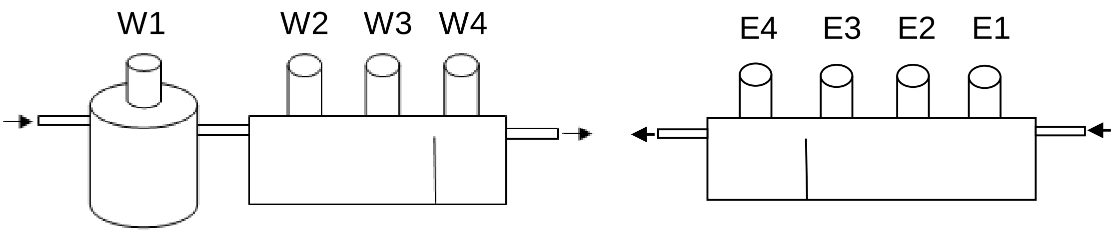


Figure 3. Tanks and sampling points (not to scale).

1.2 The aim of the project

The aim of this project was to collect data to do a system analysis were the food waste disposer system is compared to the conventional system for food waste collection, that is paper bags and separate bin.

Research questions investigated in the project:

- Source-separation ratio of household food waste in FWD-system

- Comparison between different methods for sample collection from separation tanks
- Potential biogas production in grinded food waste
- Content of organic matter and limiting components in grinded food waste
- Losses of food waste from separation tank
- Carbon footprint from FWD-system compared to conventional collection system

The overall aim of the project is to optimize the outcome of biogas from household food waste.

2. Methodology

2.1 Food waste sorting behavior

To be able to evaluate the efficiency of the waste disposer system, waste composition analyses were made of the residual waste from the area. Studying the food waste thrown in the residual waste gives a picture of the amount and the kind of food waste that is not ground in the disposers. Waste analyses were made at two times in the Fullriggaren area (September 2013 and March 2014). For comparison with food separation with paper bag an analysis was made at one time in the neighborhood area of Flagghusen (September 2014). Analyses of residual waste are made according to existing guidelines (RVF, 2005). A detailed sorting of food waste found in residual waste was made based on Vukicevic et al. (2012).

How the waste disposers are used is decided to the attitudes and behavior of the households. Therefore, a qualitative behavioral study, including interviews and observation of six households.in Fullriggaren was made by students at the Master program of Applied Cultural Analysis (MACA) at Lund University.

2.2 Technical evaluation - Methods used for sample collection, flow measurement, analyses

2.2.1 Collection of samples from the tank

The Winckler method, Method 1 below, was used for taking out the samples from the tank that were analyzed in this project. The Winckler method involves a plexi glass, gently brought down vertically in the tank. Once the tube reaches the bottom, it is sealed at the bottom. In this way a cross section of the contents of the tank is taken out. The choice of method was based on a test of different sampling methods described in the following section.

2.2.2 Comparison of different sampling methods

Three sampling methods were evaluated in connection with emptying of the tanks in January 2014, i.e. after accumulating waste for four weeks, which is the normal interval between emptying. The aim of this was to evaluate what method that would be most suitable for the project.

1. The Winckler method was used with a tube (volume about 2.8 liter) for sampling in the different wells (Figure 4). This method should take out a “column” of the tank contents and also shows how the material is distributed on the bottom and the surface.
2. In the second sampling method the tank lorry, which is used for emptying the tanks, was emptying each compartment of the respective tank at the time and then a sample was taken out from the "valve" while the lorry was back pumping the content to the tank.
3. The third method was a combination of Method 1 and 2. When the content had been pumped back to the tank compartment, a sample was taken from the tank by the Winckler tube.

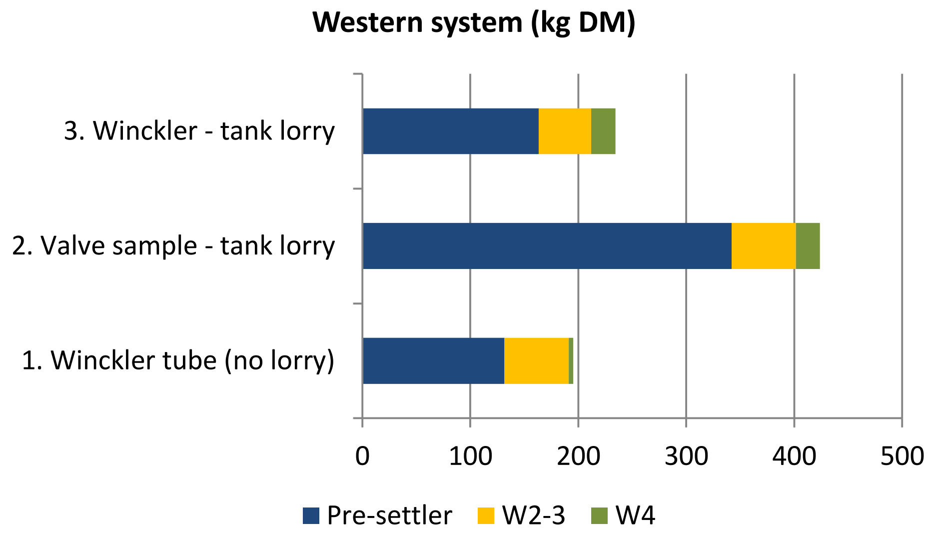
Sample volumes of 5-10 liters were taken out with all three methods.

Figure 4. Sample taken out with the Winckler tube (Method 1)

The first method gives more information than the others in form of the distribution of material on the top and bottom, which can be documented by photo and/or measuring the levels of each phase (bottom sediment, water phase and floating layer). Another advantage of this method is that it is possible to take out samples whenever it is desired during a whole collection period without disturbing the function of the tank and with moderate effort (no tank lorry is needed). It is also possible to take out separate samples from all compartments of the tanks. The disadvantage of the method is that it is hard to take out samples when the concentration of particles is high and especially when there is a dry layer, a cake, formed on the surface.

The second and third methods were based on an assumption that the tank content would be somewhat mixed during the pumping in and out from the tank lorry. This should give a higher representativeness of the samples taken out, since they would be more or less “totally mixed”. A disadvantage of the method was that a considerate amount of water had to be added to some of the compartments to be able to pump of the material, which would influence the analyses of DM and VS.

The content of DM in the collected samples was measured and used for calculating the amount of dry matter that the different parts of each system would contain according to the three different sampling methods, see Figure 5. Since only one sample could be taken out for compartments 2 and 3 in the Westerns system (W2-3) and for compartment 1-3 in the Eastern system (E1-3) with Methods 2 and 3, the amount for these compartments were summarized also for the Method 1. It is clear that the sample taken out from the lorry valve, during sampling of the pre-settler in the Western system is differing a lot compared to the other samples. For the Eastern system no such differences were seen. The valve sampling seemed most uncertain since it was not clear how the representativeness would be when taking out a sample directly from a valve and the possible mixing effect from pumping up and back the samples could not be evaluated. The advantage with the Method 3 was that there was less “cake” on the surface of the tank when the sample had been pumped back to the tank. This made it easier to sample with the Winckler tube. However, since not much difference in DM content was seen between the Method 1 and Method 3 for the Eastern system, the Method 1 was chosen. This method is simple, it does not demand a tank lorry, samples can be taken out for evaluation of the development between two emptying periods and it gives information about the function of each compartment.



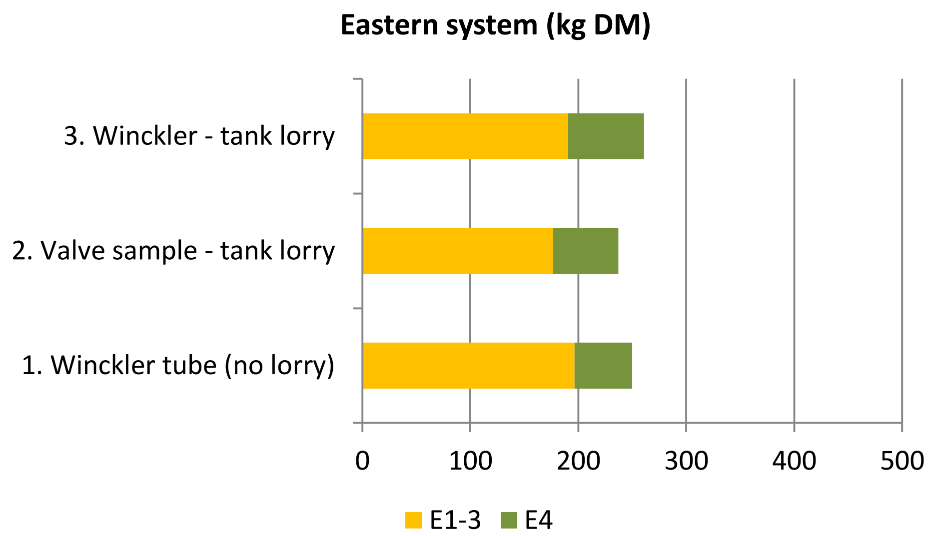


Figure 5. Amount of dry matter that the different parts of each system would contain according to the three different sampling methods.

2.2.3 Collection of samples from the tank outlet

The collection of outlet from the tank was done by pumping up liquid from the outlet channels with a peristaltic pump (see Figure 6).

Figure 6. Pump (left) used for sampling from the outlet channel (right)

2.2.4 Flow measurement

Flow measurements were done by installing a portable instrument (Portable Mainstream 04) in the manholes on the outlet channel from the tanks (Figure 7). The flowmeter, which was pressed into the pipe, registers velocity and level and from these the average flow can be derived. A polynomial calculation of the flow was made for both tanks. Polynomials were based on the level and flow ratio during periods when the meter managed to capture both the level and velocity. When no velocity was registered the flow was estimated only from the level. Data were registered every 2nd minute during the time period 2014-02-27 until 2014-03-25, with an interruption during two days (12-13 March), when the batteries had to be charged. The small size of the pipe (inside diameter 144 mm) is a bit lower than the normal range of applicability for the flow meter. Usually it is used at Ø 200 mm, but it can be used at Ø160 mm when the flow and the water level are high enough. The pipe at Fullriggaren has an inner diameter of 144 m so it had to be dammed up with a sand bag to increase the water level so the flow meter could deliver reliable values. The damming was done on the 6th of March so the earlier data were disregarded. During night time the flow was very low. This led to problems in getting data out of that period, especially for the Eastern outlet where no flow could be detected between 00-06.

Figure 7. Flow measurement sensor (left) and the installation in the outlet channel (right) with a sand bag for damming up the water level.

2.2.5 Sampling scheme

The samples were taken out during March 2014 and Sep-Oct 2014; see Table 1 for an overview. The first sampling period was used to evaluate the function of the tank by taking out several samples between two emptying occasions, a four-week period. In the second sampling period samples were taken out two weeks after emptying and then the tank was emptied and the next sampling was done after three weeks. The sampling points are shown in Table 2. During Feb-Mar, 1-2 outlet samples per tank system were taken out, but during Sep-Oct 3 parallel samples were taken out per tank system. The parameters analyzed in the samples from outlet, composite outlet samples, sludge samples from each compartment of the tank and composite sludge samples representing the whole tank are presented in the Table 3.

Table 1. Sampling scheme for sludge from tanks and outlet samples

Date	Nb of sludge samples	Nb of outlet samples
20140227	0	2
20140303	8	2
20140310	8	2
20140317	8	4
20140321	8	4
20140922	8	6
20141013	8	6

Table 2. Sampling points for the two tanks (Comp. = compartment)

Western	**Pre-settler**	**Comp. 1**	**Comp. 2**	**Comp. 3**	**Outlet**
Sample ID	W1	W2	W3	W4	Western outlet
Eastern	**Comp. 1**	**Comp. 2**	**Comp. 3**	**Comp. 4**	**Outlet**
Sample ID	E1	E2	E3	E4	Eastern outlet

Table 3. Parameters analyzed in the samples from outlet, composite outlet samples, sludge samples from each compartment of the tank and composite sludge samples representing the whole tank.

	Outlet		Outlet composite		Sludge from each compartment		Sludge composite	
	Feb-Mar	Sep-Oct	Feb-Mar	Sep-Oct	Feb-Mar	Sep-Oct	Feb-Mar	Sep-Oct
pH	x	x					x	x
SS	x	x						
DM					x	x	x	x
VS					x	x	x	x
COD-total	x	x					x	x
COD-fil	x	x					x	x
VFA	x	x					x	x
P	x			x			x	x
K	x			x			x	x
S	x			x			x	x
Al	x			x			x	x
Cd	x			x			x	x
Cr	x			x			x	x
Cu	x			x			x	x
Fe	x			x			x	x
Mg	x			x			x	x
Pb	x			x			x	x
Zn	x			x			x	x
Ag				x				x
N-tot	x	x						
NH4	x	x			x*			
Fat x 3	x			x				
C and N							x	x
Carbohydrate					x*		x	
Protein					x*			
Fat					x*			
Conductivity	x							
Chloride	x							
Sulphate	x							

*Carbohydrate, protein, fat and ammonia were analyzed in the sludge from each tank compartment taken out 2014-03-21.

2.2.6 Sample preparation

The samples were stored in cold room (+6˚C) for up to 24 hours before analysis or before preparation for later analysis. The externally analyzed samples were stored in freezer after preparation. Some of the parameters were determined directly on the raw outlet samples, while others (see Table 3) were determined on composite samples. The composite samples were prepared for outlet samples taken out in parallel by mixing equal amounts of each sample. For the sludge samples from the tank initial analysis were made on each sample taken out of each compartment of the tanks. Then composite samples were made for each tank system by mixing a part of the samples from the compartment according to the volume each compartment represents, see Table 4.

Table 4. Distribution of tank volume on different compartments in percentage of total tank volume and total volume of each tank system.

Western	**Pre-settler**	**Comp. 1**	**Comp. 2**	**Comp. 3**	**Total tank volume**
Part of total volume	72,0%	5,8%	11,7%	10,5%	7.1 m^3
Eastern	**Comp. 1**	**Comp. 2**	**Comp. 3**	**Comp. 4**	**Total tank volume**
Part of total volume	25,4%	25,4%	25,4%	23,8%	5,6 m^3

2.2.7 Analysis methods

Analyses were performed at two external accredited laboratories, Eurofins and Alcontrol and at two laboratories at Lund University: the department of Chemical Engineering (VA-teknik) and at the inorganic laboratory at the department of Biology. A list of used methods is found in Table 5.

Table 5. Methods used for analyses of the different sample types (S= sludge from tank, O= tank outlet)

Parameter	Sample type	Method/Instrument	Lab
pH	S, O	With a WTW instrument, model 320	Dept. of Chemical Engineering, LU
DM, VS, SS	S, O	Standard methods (APHA, 2005)	
VFA	S, O	Centrifugation in Centronix Microcentrifuge, Model RPM X 1000 and filtration with Munktell 1002, 110 mm. analysis with gas chromatograph (Agilent 6850 Series) equipped with a HP-FFAP column (30 m/0.53 mm/ 1µm) at 80–130 ˚C (temperature inlet flow 180 ˚C, oven temperature 260 ˚C). Results in form of concentrations of acetate and propionate in mg COD/L.	
COD_f, NH_4^+, SO_4^{2-},	S, O	Centrifugation in Centronix Microcentrifuge, Model RPM X 1000 and filtration with Munktell 1002, 110 mm before analysis in Hach-Lange Model DR 2800	

COD_{total}	S, O	Analyzed with Hach-Lange Model DR 2800	
N, Cl^-	O	Outlet samples analyzed with Hach-Lange Model DR 2800	
Conductivity	O	Outlet samples analyzed with WTW Cond 340i	
Fat x 3	O	FTIR, total and emulsified fat acc. former SS028103 mod(perchlor), separable fat calculated	Alcontrol
Ag	S, O	SS-EN ISO 11885-2:2009 (S) ISO 17294, acid extraction (O)	Alcontrol
Protein, Kj-N, NH_4^+	S	Calculated as N*6.25, Kj-N analyzed according to EN 13342, NH_4^+ analyzed as in STANDARD METHODS 1998, 4500 mod	Eurofins
Carbohydrate	S	Carbohydrates were calculated according to SLV FS 1993:21	
Ash content	S	Calculated from TS and VS determined by SSEN 12880 and SS EN 12879	
C, N	S	Dried samples analyzed in a Vario MAX N/CN	Dept. of Biology, LU
Al, Cd, Cr, Cu, Fe, K, Mg, P, Pb, S, Zn	S, O	March samples: elementary analysis with inductively coupled plasma atomic emission spectroscopy (ICPAES) (PerkinElmer model OPTIMA 3000 DV Sept-Oct samples: elementary analysis during Sept-Oct with ICP OES, model PerkinElmer, Optima 8300. Sludge samples were digested with HNO_3 and H_2O according to SS-02 81 50 before analysis	

2.2.8 Method for biochemical methane potential (BMP)

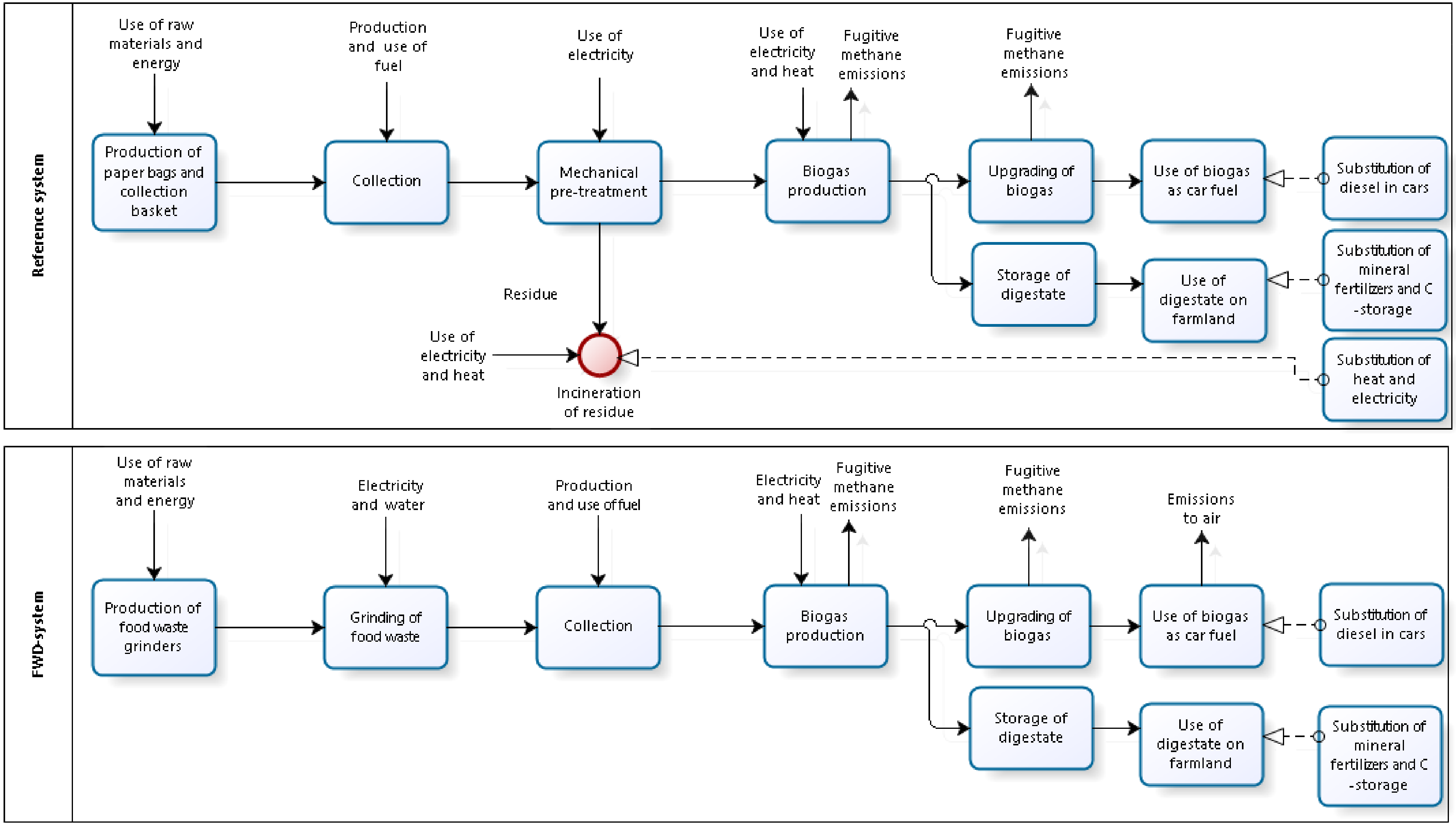
The potential methane production from ground food waste was determined with the batch tests method described in Hansen et al. (2003). Inoculum was collected from a full scale digestion plant at Sjölunda Wastewater treatment plant in Malmö. Inoculum and substrate were added in a ratio of 3:2 in relation to the VS content. The BMP of all substrates were determined in triplicate reactors. The samples were digested in an incubator at 37˚C. Cellulose was also digested as a reference to check the function of the inoculum. Gas production was measured by withdrawing samples of gas by a gas-tight syringe and analysis in an Agilent 6850 series with FID and a HP-1 column (30 m/0.32 mm/0.25 um), inlet temp 50 ˚C, detector temp 200 ˚C.

2.3 Systems analysis

2.3.1 Compared systems

The purpose of the systems analysis is to evaluate the FWD-system from an environmental perspective and compare it to a reference collection system. The aim is thus to make a statement about which of the compared systems that is more advantageous from an environmental perspective, and the conditions under which this is true. In addition, the processes giving the largest contribution to positive and negative environmental impacts are identified, as this is an important contribution for further optimization of the system. Collection of food waste in paper bags was selected as the reference system (RS), as this currently is the most common system for separate food waste collection in Sweden (Avfall Sverige, 2014), and also the dominating system in the city of Malmö. Collection of food waste from households is in Malmö performed by two-compartment vehicles, where residual waste and food waste are collected at the same time. This was also assumed to be the case in the RS modeled in the systems analysis.

The functional unit (FU) used in the study is defined as: "Management and treatment of 1 ton dry matter (DM) separately collected food waste from households." The chosen FU does not consider that the amount of source-separated food waste can be different in the compared systems. Losses of organic matter from the sedimentation tank to the sewer system are excluded from the assessment. Thus, neither negative nor positive effects related to this flow later down in the sewage and wastewater treatment system are considered, due to current lack of knowledge of how the downstream system is affected by FWD. Compared systems are presented in Figure 8.



Reference system
Use of raw materials and energy
Production and use of fuel
Use of electricity
Use of electricity and heat
Fugitive methane emissions
Fugitive methane emissions
Production of paper bags and collection basket
Collection
Mechanical pre-treatment
Biogas production
Upgrading of biogas
Use of biogas as car fuel
Substitution of diesel in cars
Storage of digestate
Use of digestate on farmland
Substitution of mineral fertilizers and C -storage
Residue
Use of electricity and heat
Incineration of residue
Substitution of heat and electricity
FWD-system
Use of raw materials and energy
Electricity and water
Production and use of fuel
Electricity and heat
Fugitive methane emissions
Fugitive methane emissions
Emissions to air
Production of food waste grinders
Grinding of food waste
Collection
Biogas production
Upgrading of biogas
Use of biogas as car fuel
Substitution of diesel in cars
Storage of digestate
Use of digestate on farmland
Substitution of mineral fertilizers and C -storage

Figure 8. Overview of compared systems for separate collection of household food waste. FWD = Food waste disposer system. RS = Reference system (collection of household food waste in paper bags).

The study is limited to an investigation of the two collection systems from a climate change perspective. Only those processes generating emissions that contribute to global warming are taken into account in the study, limited to the main greenhouse gases fossil carbon dioxide, methane and nitrous dioxide, using IPCC 2007 conversion factors (Ecoinvent Center, 2010) (Appendix 1). The study also includes an energy balance. The energy balance is made on the basis of primary energy conversion factors (Appendix 1).

As the present study has the aim to identify effects of a potential change in current waste management system, a marginal perspective was seen as the most relevant, and applied in relation to energy used and substituted in the system. Mattsson et al. (2003) assume that marginal electricity in the EU in the long term will be based on natural gas. The same assumption is made in this study. In the case of heat, however, average data for fuels currently used for district heating in Sweden are used, based on Gode et al. (2011). It is assumed that produced biogas is used in the transport sector to replace diesel. Environmental impacts from the production and combustion of diesel are based on Gode et al. (2011).

Methane production from collected food waste is in the FWD-system based on batch methane potential tests performed within the project, while methane production from food waste collected in the reference system was based on literature data (Truedsson, 2010). A degradation factor of 80% is assumed in the reference system, based on Davidsson et al. (2007), while 90% is assumed in the FWD-system, based on results presented in section 3.2.8

Digestate is in both compared systems used as fertilizers on farmland, where macronutrients (N, P and K) substitute mineral fertilizers with a substitution rate of 100%. Further discussion related to the chosen substitution rate is found in Appendix 2.

As the systems analysis is conducted as part of an evaluation of a full-scale tank connected system, primary data was in many cases used for modeling of the FWD-system. In the description of the reference system, however, literature data was used. Input data used in the analysis is presented in Appendix 3.

3. Results and discussion

3.1 Food waste sorting behavior

3.1.1 Waste composition analyses

Results from the waste composition analyses of residual waste performed in September 2013 and September 2014 are presented in Figure 9. Results show a decrease in the total amount of non-separated food waste between the two analyses, although the profile of non-separated food waste in general remains the same. Figure 9 also displays results from a waste composition analysis performed in the quarter Flaggskepparen, an area nearby the study area in the Western Harbor, with separate collection of food waste in paper bags. Results show a composition of non-separated food waste similar to the one in the study area (Fullriggaren), while the amount of non-separated food waste is close to the average from the two analyses performed in Fullriggaren.

Results from the analyses performed within this study are in Figure 9 also compared to analyses performed in 2012 in five municipalities in southern Sweden (Vukicevic et al, 2012). In all cases, analyzed food waste samples were collected from multi-family buildings with separate collection of food waste in paper bags (i.e. the same system as in Flaggskepparen). However, data presented in Figure 9 reflects the amount and composition of food waste found in residual waste (i.e. not separated by households). The comparison shows that the amount of food waste in residual waste is low in both areas in the Western Harbor, compared to multi-family dwellings in other municipalities in the same geographical region. However, the composition of non-separated food waste is very similar in samples from all multi-family dwellings, independent of collection system (i.e. paper bags or FWD). Based on results generated in the present study, it is not possible to determine any general difference in food waste separation behavior between areas with FWD and separation of food waste in paper bags.

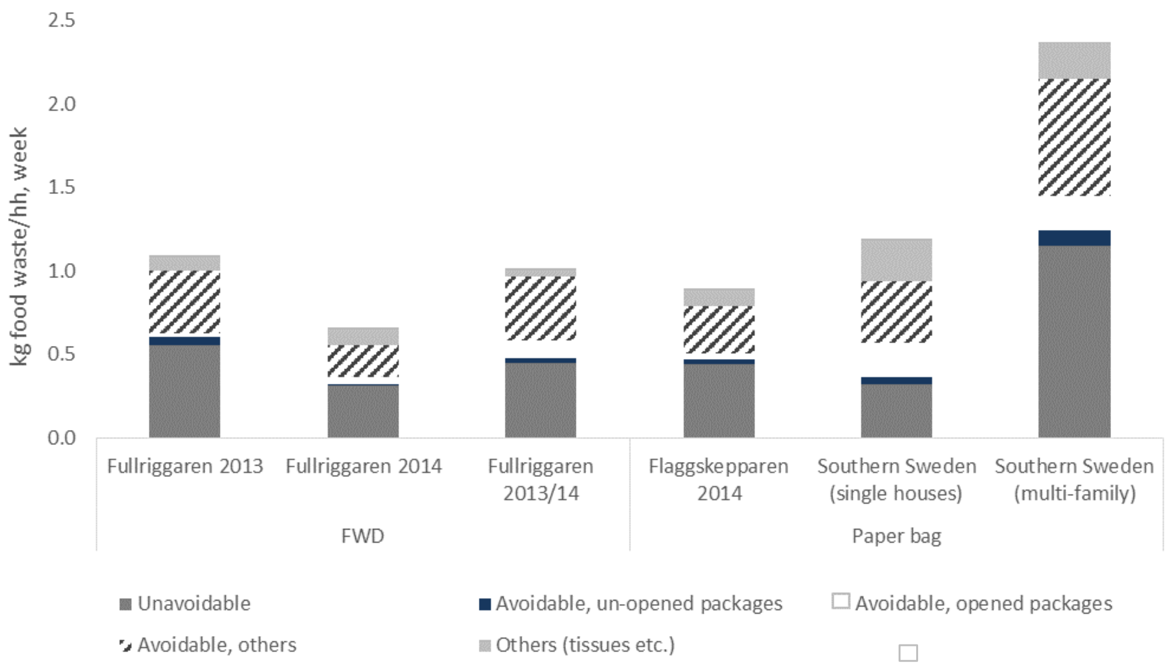


Figure 9. Results from waste composition analyses performed on food waste found in residual waste in the study area and in other municipalities in southern Sweden.

3.1.2 Behavioral studies

The behavioral study at Fullriggaren showed that some food waste not is considered grindable by the households, for example larger bones, nutshells and skin from some types of fish. It could also be the problem that the hole in the sink is too small. A few technical issues were also mentioned in the interviews, for example loud sounds, vibrating kitchen benches and clogged pipes.

Five out of six interviewed household have grown more comfortable to the waste disposer. Most of them have earlier had issues of some sort, but with time, for example learnt that some waste is not fit for grinding or adapted to the fact that the noise is too loud to use the disposer after the children have gone to bed. Only one household has stopped using the disposer due to negative experiences.

3.2 Technical evaluation

3.2.1 Tank content

The characteristics of the composite samples, representing the whole tank content, are shown in Table 6-7. The sampling period in March 2014 can be used to evaluate the development in the tanks during a longer period. The results show that the solids content is increasing with time since the waste is accumulating in the tanks (also seen in Figure 10). The increase of DM is lower at the end of the sampling period (after 21 days), indicating that the capacity of the tank is reached. It should also be noted that it was harder to take out samples of the compartments with high solids, especially when there was a thick layer of dried out organic matter on the surface, which was blocking the inlet to the sampling pipe. This could have influenced the representativeness of the samples and thereby the results at the end of the sampling period. This is probably the reason for the stagnation in dry matter seen in the Western tank from 21-25 days. The largest difference between the tanks is that for the Western system the majority of the waste is settling in the first compartment (W1 in Figure 10). This is logical since this compartment, which is a deep circular pre-settler, occupies 73% of the total volume. In the Eastern system the waste is distributed more evenly throughout all compartments. It can be noted that also the fourth compartment (E4), contains a lot of waste, especially after 25 days. This compartment is meant for separation of fat and should not contain much settled matter, since the wall between compartment E3 and E4 should hinder this. Figure 11 shows the sample taken out from E4 after 25 days. There is a lot of waste in the whole compartment, both settled particles and floating fat.

The DM seen after 21-25 days was in average 3.8% for the Western tank and 4.4% for the Eastern tank. This can be compared to the average DM in samples taken in the separation tank after 28 days for the previously studied area Turning Torso (also in Malmö) which was 2.7% with a standard deviation of 1.5% (Davidsson et al, 2011). The results from Fullriggaren show that the tank can thicken waste to a higher DM content than was previously seen. They also indicate that the loading of grinded waste is much higher in Fullriggaren than in Turning Torso.

The pH is decreasing during the time period and meanwhile the volatile fatty acids and dissolved COD is increasing (Table 6-7), which could be explained by hydrolysis of organic matter. A fast decrease in pH was also seen during laborative hydrolysis tests performed with grinded food waste in Davidsson et al. (2011). In that study the pH dropped from 7 to around 4-5 in 1-2 days.

The pH is lower in the Eastern tank, which could indicate a more extensive hydrolysis of organic matter, but the dissolved COD and VFA concentrations are not higher for the Eastern tank. The hydrolysis might on the other hand be partly inhibited by the low pH in the Eastern tank. It is not likely that the grinded waste would differ in pH for the two systems. The difference in pH must therefore be caused by the different construction of the systems, where the deep pre-settler in the Western system is the major difference. More specific studies would be needed to clarify how the difference in construction is affecting pH. There was not much difference between total COD in the two systems. However there are limitations in the analysis method for COD that require dilution with water several times.

Table 6. pH, DM, VS, COD, CODfiltrated and VFA (acetate + propionate) in the Western tank during the two sampling periods.

	Time (days)	pH	DM (%)	VS (%)	CODt (mg/L)	CODf (mg/L)	VFA (mg COD/L)
20140303	7	5.47	0.91	0.84	11960	1834	922
20140310	14	5.07	1.98	1.89	20080	2238	1457
20140317	21	5.00	3.4	3.13	44440	4910	2283
20140321	25	4.95	3.87	3.7	62400	5170	2312
20140922	14	5.26	1.28	1.2	20600	2960	1134
20141013	21	5.24	4.02	3.77	90300	6200	2982

Table 7. pH, DM, VS, COD, CODfiltrated and VFA (acetate + propionate) in the Eastern tank during the two sampling periods.

	Time (days)	pH	DM (%)	VS (%)	CODt (mg/L)	CODf (mg/L)	VFA (mg COD/L)
20140303	7	4.90	0.83	0.77	9500	1640	878
20140310	14	4.62	2.85	2.73	37240	3788	2022
20140317	21	4.69	3.74	3.62	44400	4500	2440
20140321	25	4.61	4.84	4.52	66200	6250	3308
20140922	14	4.84	2.97	2.86	53800	4790	1821
20141013	21	5.01	4.52	4.3	68600	6540	2544

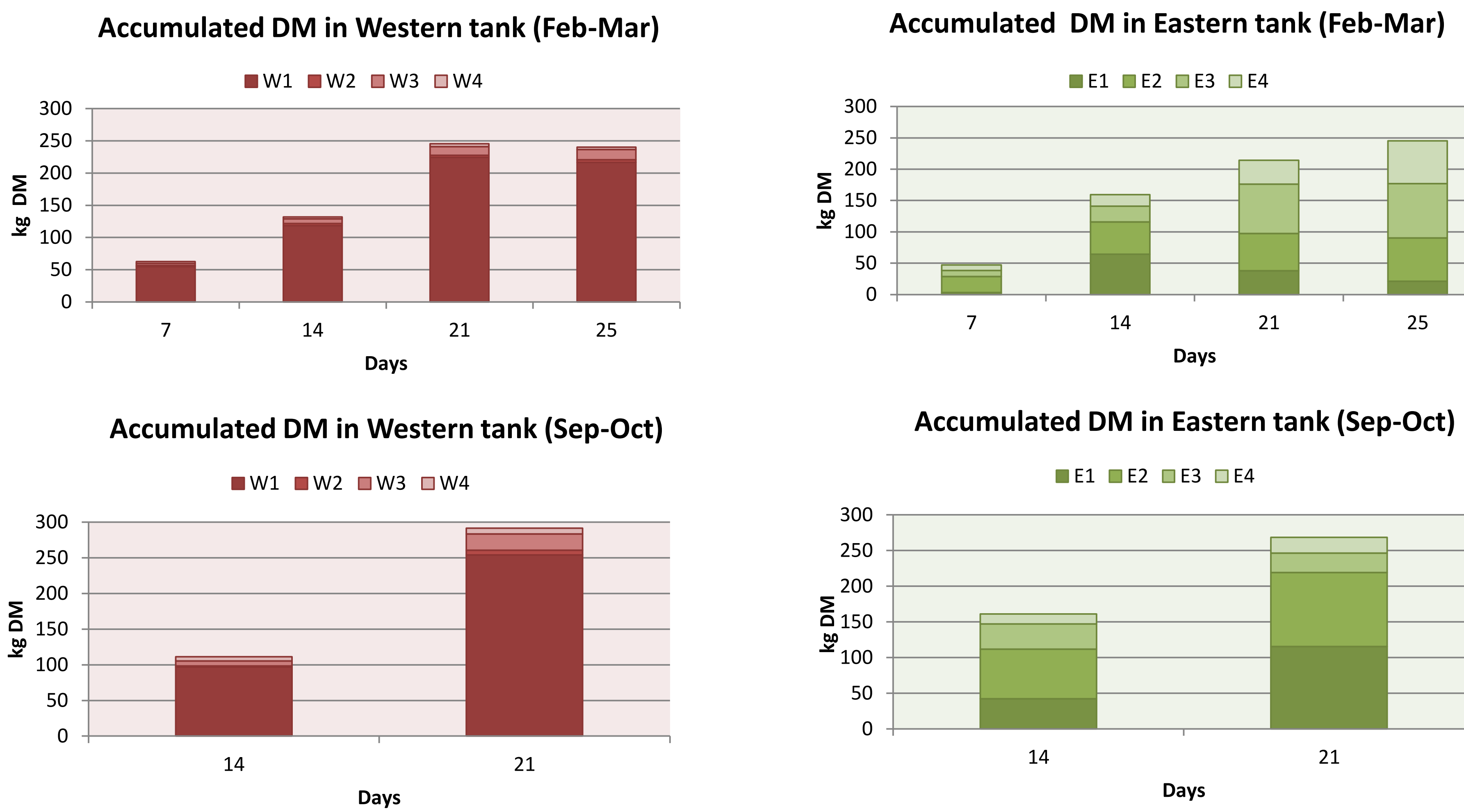


Figure 10. Distribution of the waste in the tanks compartments during the two sampling periods. N.B. during the 1st sampling period (Feb-Mar) samples were taken out through a four-week-period, from emptying to emptying. During the 2nd sampling period, sampling were done two weeks after emptying, then the tank was emptied and another sampling followed three weeks later.

Figure 11. Sample taken out from the fourth compartment of the Eastern tank after 25 days.

The yield of waste is represented by the amount of waste that could be collected from the tanks. Using the DM-content (accumulated) in the samples at different sampling times, the daily yield per household can be calculated for each of the tanks during each time period together with the average, see Table 8. The average yield is slightly higher for the autumn. The reason is that the yield is going down after 21 days during spring. This effect is not included during autumn since no sampling after 25 days was done. The yield is higher for the Eastern tank than for the Western tank.

Table 8. Yield as amount of waste ending up in the tanks per day according to the results from the sampling.

Western tank (kg DM/hh/d)					
(days)	7	14	21	25	**Average**
Feb-Mar	0.026	0.028	0.034	0.028	**0.029**
Sep-Oct		0.023	0.041		**0.032**

Eastern tank (kg DM/hh/d)					
(days)	7	14	21	25	**average**
Feb-Mar	0.025	0.042	0.037	0.036	**0.035**
Sep-Oct		0.042	0.047		**0.045**

The elementary analysis results of the composite samples from the tanks are shown in Table 9. Cd concentrations were below or on the detection limit in all spring samples. The detection limits for the analysis of Cd (and also Cr and Pb) were lowered during the summer, so in the autumn samples a low concentration of Cd was seen for both systems. The cadmium concentrations are low compared to the current limits for sludge on farmland, 2 mg/kg DM (SEPA, 1994) and also compared to the limits in the certification system for digestate from biogas plants (without sewage sludge), 1 mg/kg DM (Avfall Sverige, 2013). Food waste from the studied system could both be digested at a WWTP together with sewage sludge or at other biogas plants (without sewage sludge). The ratio between cadmium and phosphorus, however, is between 30-47 mg Cd/kg P, which is on the limit of what the REVAQ certification system allows as average yearly value for sewage sludge going to farmland, 34 mg Cd/kg P. Sewage sludge contains much higher concentrations of phosphorus than food waste. The average concentration of the sludge at Sjölunda WWTP was 31250 mg P/kg DM according to the environmental report 2013 (VA SYD, 2014).Thus, the relatively high Cd/P-ratio found in the tank content can primarily be seen as an effect of the relatively low phosphorus content in food waste.

Similarly low concentrations of phosphorus and high Cd/P-ratios have been seen in previous analyses of separately collected food waste. An average phosphorus concentration of 1641 mg P/kg DM was found for food waste analyzed in a study by Biogas Syd (2012). The corresponding ratio of Cd/P was 69 mg Cd/kg P. The reported value for food waste from Malmö sorted out in paper bag and pretreated with screwpress was 51 mg Cd/kg P (Truedsson, 2010).

The copper concentrations are higher than the limit value for all samples from the Eastern tank and for some samples from the Western tank. The zinc concentration is higher than the limit for some of the Western samples, but not for the Eastern samples. Lead concentrations are low compared to the limit value.

Silver was only analyzed in the autumn samples. The reported Ag concentrations (0.81-1.1 mg/kg DM) are below or on the detection limit (1 mg/kg DM) for all samples. These concentrations can be compared to the average yearly concentration in the sludge at Sjölunda WWTP in Malmö, which is 2.2 mg Ag/kg DM.

The C/N ratio is on average 18 (for both tanks), which is within the optimum range for anaerobic digestion, 15-25 (Jarvis & Schnürer, 2009).

Table 9. Elementary composition of the tank content at different sampling times (days after tank being emptied) in the Western and Eastern tanks (mg/kg DM). Limits for sludge to farmland by Swedish EPA (SEPA, 1994) and concentrations found in a reference slurry (food waste sorted out in paper bags and pretreated by screwpress) (Truedsson, 2010).

Western	Time (d)	**Al**	**Cd**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**P**	**Pb**	**S**	**Zn**	**Ag**	**C**	**N**
20140303	7	573	n.d.	n.d	65	171	4357	1045	3345	0.76	3364	98	n.a.	536000	22000
20140310	14	492	n.d.	n.d	48	142	2374	575	2674	0.53	2486	71	n.a.	568000	32000
20140317	21	489	n.d.	n.d	51	143	1964	440	2386	0.71	2175	74	n.a.	563000	35000
20140321	25	415	n.d.	0.25	47	135	1544	455	2203	0.70	2270	70	n.a.	557000	38000
20140922	14	945	0.09	1.46	58	222	2463	772	2816	1.17	2395	88	<1.1	572000	32000
20141013	21	1080	0.14	2.43	115	427	2652	788	4539	2.79	3503	143	<0.81	567000	28000
Limit			2.00		60					10		80			
Reference slurry			0.19	36	18		11800	1200	3700	1.1	2600	100			24000

Eastern	Time (d)	**Al**	**Cd**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**P**	**Pb**	**S**	**Zn**	**Ag**	**C**	**N**
20140303	7	98	n.d	n.d.	104	185	4029	907	2669	1.27	2876	35	n.a.	580000	23000
20140310	14	108	0.100	n.d.	134	191	2160	466	2311	1.07	2269	35	n.a.	578000	36000
20140317	21	132	0.100	n.d.	129	178	1697	381	2222	1.45	2249	40	n.a.	590000	36000
20140321	25	134	0.101	n.d.	152	214	1454	387	2359	1.49	2537	42	n.a.	585000	37000
20140922	14	201	0.136	1.85	101	289	2109	622	2881	2.24	2808	51	<0.91	603000	30000
20141013	21	672	0.129	1.68	238	329	1939	517	3763	2.05	2864	48	<0.92	583000	35000
Limit			2.00		60					10		80			
Reference slurry			0.19	36	18		11800	1200	3700	1.1	2600	100			24000

3.2.2 Organic matter content

The organic matter in the tank content was characterized by analyzing protein, fat and carbohydrates in samples taken out in the end of the first sampling period (21 March 2014). The objective was partly to find out if the last compartment (W4 or E4), the fat separating step of each system, actually separates more fat than the others. The results are seen in Table 10. Since the fat content is higher in the last compartments on both systems, it can be concluded that this step is working as a fat separation step. It can also be noted that for the Western tank system, quite a lot of fat is also ending up in the 2nd and 3rd compartments. Besides that, not much difference between the tank systems can be seen. Both tank systems are separating much of the carbohydrates in the beginning of the tank. The calculated total distribution is quite equal, even if the Eastern system seem to separate a bit more fat and less carbohydrates than the Western system. The total ash content is 3% for both systems. A low ash content means a high organic content and a high potential for biogas production. The ash content in food waste from various sorting systems and pre-treatment methods were on average 13% (calculated value) in a study by Davidsson et al (2007) and in Carlsson & Uldal (2009) food waste is stated to have a corresponding ash content of 15%. The ash content in the pre-treated food waste slurry in Truedsson (2010) was 7.8% of the DM.

Table 10. Contents of protein, fat, carbohydrate and ash (% of DM) in samples taken from the tank (different compartments) 2014-03-21 (25 days after emptying). Total Western and Total Eastern are calculated values.

	Protein	**Fat**	**Carbohydrate**	**Ash**
W1	23%	29%	45%	3%
W2-3	25%	52%	16%	6%
W4	18%	50%	18%	14%
Total Western	*23%*	*31%*	*43%*	*3%*
E1-3	23%	29%	45%	4%
E4	25%	52%	16%	2%
Total Eastern	*24%*	*36%*	*37%*	*3%*

3.2.3 Temperature

At each sampling occasion, the temperature in the first part of each tank system was noted. The results are found in the Figure 12 together with the corresponding daily average air temperature in Malmö. The temperature in the tank is in all cases higher than the air temperature, since the samplings were done during winter-spring and autumn. The high temperature in the tank is explained by the fact that a lot of hot water is used in the kitchen (dishing). A high temperature increases the risk of hydrolysis of organic matter and thereby the risk of loss of food waste to the outlet. The hydrolysis rate is increasing exponentially according to the Arrhenius equation and is in theory twice as high at 20˚C as at 15˚ C. The temperature in the Eastern system is lower in the western system. This is probably caused by the differences between the systems. The Western system has a deep pre-settler in concrete, which is not the case for the Eastern system, see Figure 3.

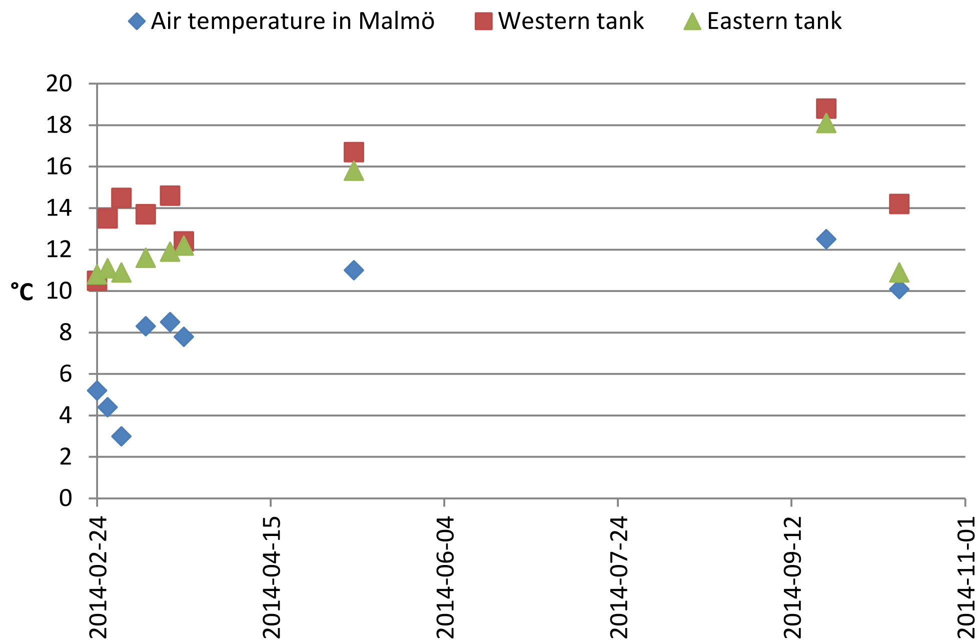
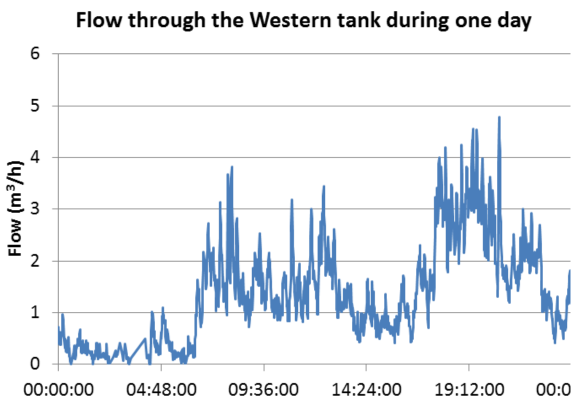


Figure 12. Registered temperatures in the tanks during the sampling periods and corresponding air temperatures.

3.2.4 Flow

The flow measurements show that the flow is varying a lot over the day, see Figure 13. For the Western tank it can be seen that during night time (00-04), there is almost no flow, and during the rest of the day the flow is varying between 0.5-5 m^3/h. For the Eastern tank, no flow were detected between 00-06, and the rest of the day the registered flow is in general much lower than for the Western tank. The same pattern (with no flow between 00-06 for the Eastern system) is seen for the other days in the measuring period. It is reasonable to have little or sometimes no flow during 00-06 in this type of area, but it is not expected that there will never be a flow at night time during the whole test period (4 weeks), which was seen for the Eastern system. It is probable that the measurements were not registering the whole flow for the Eastern tank system.



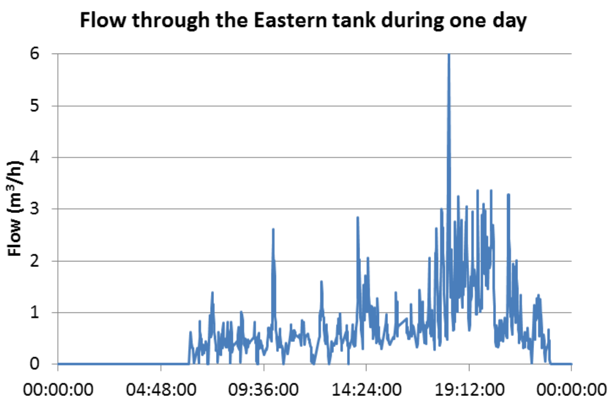


Figure 13. Flow variation during a "typical" 24-hour period (17th of March 2014) for the two tank systems.

The results in form of daily amount of water passing the tanks during the part of the test period that was considered "stable" are shown in Figure 14.

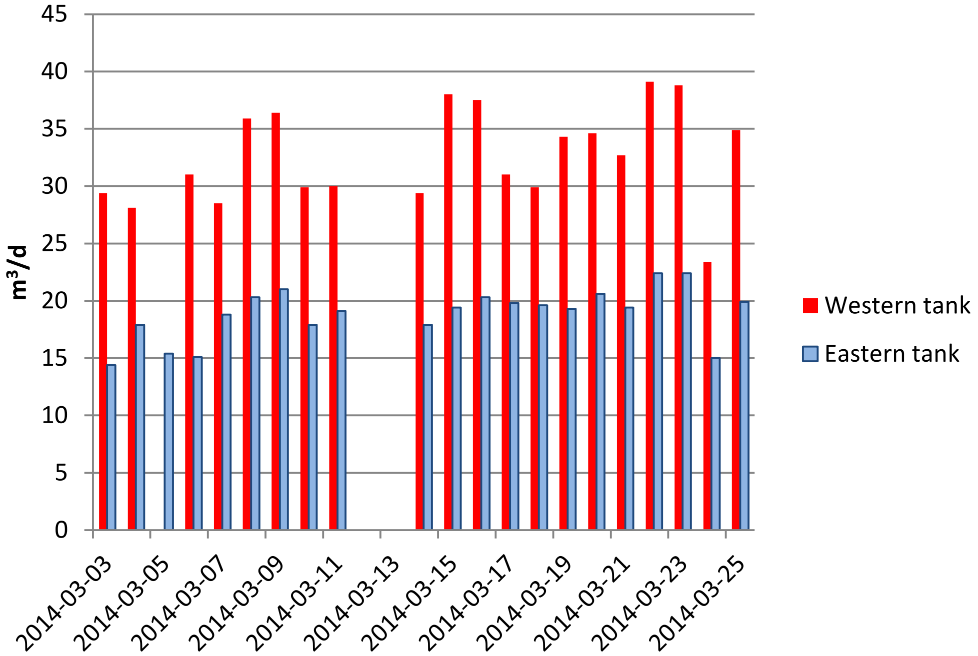


Figure 14. Daily flow measurements for the two tank systems. The batteries were on charge 12-13 March.

The measurement gives the level and the speed of the water and a polynomial method that uses both was used to calculate the flow. The low registered flow in the Eastern tank during nighttime explains the big difference between the systems. Another thing contributing slightly to the difference is that the number of households connected to the Western tank is higher (341 households) than for the Eastern tank (273 households). In Table 11 the measured flows are converted to flow per household and compared to the average consumption of water in kitchens from Sydvatten (2014) assuming a household size of 2.4 persons. The Western flow seems to be reasonable, but the Eastern flow is lower than expected. This motivates to use the flow from the Western tank in the mass balances in the following sections. It can be noted that households with waste disposers are not expected to give higher water consumption than other households according to the study by Mattsson & Hedström (2012). That study showed that water consumption rather decreased when waste disposers were introduced.

Table 11. Measured flow and calculated consumption in comparison to key figures on water consumption in kitchen.

	Western	Eastern	Expected water consumption
Flow (m^3/d)	33.6	19.9	
liter/hh/d	98.5	72.9	108*

*Using key figure for water consumption in kitchen: 45 liters/PE/d from Sydvatten (2014) and assuming 2.4 PE/hh,

3.2.5 Outlet analyses

The analysis results for the outlet are found in the Table 12-13. The pH is varying between 5.60-6.38 for the Western outlet and 4.89-5.65 for the Eastern outlet. This means that the pH is a bit lower than the recommendation, pH 6.5-10, in the VA SYD guideline (VA SYD, 2010). A lower pH in outlet can increase the risk of corrosion in sewer pipes. However the pH can be expected to increase when the outlet is mixed up with sewage from the bathrooms. The pH is lower in the Eastern outlet for all samples. There is also a tendency that the pH is decreasing with the time from tank emptying in the Eastern outlet. There is no such tendency for the Western outlet.

The SS-concentrations are on average 187±59 mg/L for the Western outlet (excl the deviant value on the 21 March, when the sample was contaminated by sediment) and 187±64 mg/L for the Eastern outlet. This could be compared to the average concentration at the inlet of Sjölunda 2013, which was 266 mg SS/L (VA SYD, 2013). A hypothesis is that the suspended solids concentration would be higher the longer the time after tank emptying. This is however not clearly seen. The same variation is seen for total COD as for SS. When the SS is high, the COD is in general also high. A slightly lower COD is seen for the Western outlet (1193±178 mg/L) than for the Eastern outlet (1351±188 mg/L). The COD after filtration of samples is 1110 mg/L and 966 mg/L (average for Eastern and Western respectively) which corresponds to 81% of the total COD, meaning that most of the COD in the outlet is dissolved COD. This means that the tank is able to separate most of the particulate COD, but naturally the dissolved COD will not be separated in a simple separation tank as the one used in this system. The dissolved COD could be a result of hydrolysis in the tank, but some of it is probably already dissolved in the grinded waste and kitchen wastewater entering the tank. The ratio of CODfiltrated/CODtotal in the tank content is relatively constant during the sampling period in Feb-Mar, which indicates that not so much hydrolysis is going on. No sampling of the inlet was done even though it would be interesting to analyse COD in the inlet to the tank. However only grab samples would be possible to get and the composition of the inlet is expected to vary a lot so the representativeness can be expected to be low.

When it comes to nitrogen content, there are some differences between the two systems. The Western outlet has a higher total nitrogen content and also a much higher part is in form of ammonium, almost 50%. At pH<7, all Ammonia-N will be in form of ammonium, NH_4^+. The higher nitrogen concentration indicates that more organic matter has been hydrolyzed in the Western tank and thereby more dissolved nitrogen in form of ammonium ends up in the outlet. Veeken et al (2000) showed that the hydrolysis rate for biowaste is decreasing with low pH, because of inhibition from pH < 5.5. In general, the Eastern tank has a lower pH than the Western tank, so it is possible that the hydrolysis rate is higher in the Western tank. On the other hand, the concentrations of acetate, propionate and COD after filtration are not higher in the Western outlet or in the Western tank (see Table 12), which does not support the theory.

The sulphate concentration is low compared to the recommended max value (even if it also includes SO_3^{2-}, $S_2O_3^{2-}$). The sulphur concentration (in Table 12-13) shows that most of the sulphur is in sulphate form (1 mg/L of S corresponds to 3 mg/L of SO_4^{2-}). Therefore, the sulphate concentration was not analyzed during the autumn sampling. Chloride and conductivity were also much lower than the max value in the guideline (VA SYD, 2010) and were therefore not measured during the autumn.

Table 12. Analysis results for the Western outlet together with recommendations from VA SYD about sewage quality (for some parameters). (Time = days after emptying the tank)

	Time	pH	SS	COD	COD_f	N	NH_4^+	[4]SO_4^{2-}	Acetate	Propionate	Chloride	Conductivity
Western outlet	days		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mS/m
20140227	3	6.38	166	971.0	851	54.6	22.7	42.2	205	90.0	69.4	91.6
20140303	7	6.07	134	1120	978	56.4	28.7	48.6	239	151	81.6	99.7
20140310	14	5.89	204	1462	1190	51.8	36.2	34.6	279	181	74.7	92.0
20140317 am	21	5.67	175	1216	922	48.6	26.7	40.8	272	167	79.6	85.2
20140317 pm	21	6.19	310	1410	980	73.6	46.7	32.6	266	169	73.5	98.7
20140321 am[1]	25	5.90	1100	3090	1020	90.0	31.6	36.7	301	184	76.1	95.5
20140321 pm	25	6.38	182	1454	1120	24.6	4.14	27.3	311	262	75.9	115
20140922	14	6.18	181	1053	853	42.8	33.3		230	201		
20141013	21	5.63	175	1175	982	41.8	22.9		214	179		
ABVA + VA SYD		6.5-10	40				60[2]	400[3]			2500	500

[1] Deviant values for SS, COD and N-tot. Since the flow in the outlet channel was very low at the sampling occasion, it is likely that the sample was contaminated by sediment in the channel.
[2] The guideline recommends that NH_3 + NH_4^+ <60 mg/L.
[3] The guideline recommends that sum of SO_4^{2-}, SO_3^{2-}, $S_2O_3^{2-}$ <400 mg/L.
[4] Some reported values are below the detection limit, 40 mg/L.

Table 13. Analysis results for the Eastern outlet together with recommendations from VA SYD about sewage quality (for some parameters) (Time = days after emptying of the tank)

	Time	pH	SS	COD	COD_f	N	NH_4^+	SO_4^{2-}	Acetate	Propionate	Chloride	Conductivity
Eastern outlet	days		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mS/m
20140227	3	5.59	139	1210	887	27.0	2.04	26.4	123	136	90.0	79.3
20140303	7	5.65	240	1176	929	24.2	4.43	41.7	228	151	72.8	76.0
20140310	14	5.26	145	1346	1140	16.6	5.68	28.3	276	223	74.8	76.1
20140317 am	21	5.06	279	1632	1240	25.6	3.12	43.6	1240	2086	104	90.1
20140317 pm	21	5.08	214	1412	1080	23.4	2.49	15.1	247	191	83.2	72.6
20140321 am	25	4.95	326	1756	1270	23.7	4.37	13.3	340	374	88.4	82.4
20140321pm	25	5.56	227	1122	904	26.5	5.80	42	266	178	68.0	81.7
20140922	14	5.31	131	1213	1062	16.8	2.95		303	284		
20141013	14	4.92	157	1422	1265	18.8	3.40		273	253		
ABVA + VA SYD		6.5-10	40				60[1]	400[2]			2500	500

[1] The guideline recommends that $NH_3 + NH_4^+ < 60$ mg/L

[2] The guideline recommends that sum of SO_4^{2-}, SO_3^{2-}, $S_2O_3^{2-}$ <400 mg/L

Table 14. Results from elementary analysis of the Western outlet. (Time = days after emptying of tank)

Western (mg/L)	**Time**	**Al**	**Cd**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**P**	**Pb**	**S**	**Zn**
		mg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	mg/l	mg/l
20140227	3	0.758	n.d	n.d	0.072	0.211	27.8	7.99	5.05	n.d	12.43	0.055
20140303	7	0.232	n.d	n.d	0.045	0.385	33.4	7.11	6.55	n.d	12.25	0.045
20140310	14	0.485	n.d	n.d	0.046	0.266	32.3	6.01	7.58	n.d	8.37	0.073
20140317am	21	0.414	n.d	n.d	0.052	0.189	29.5	5.52	5.98	n.d	9.21	0.034
20140317am	21	0.629	n.d	n.d	0.062	0.220	28.8	6.32	9.59	n.d	10.17	0.111
20140321pm	25	2.901	n.d	n.d	0.158	0.177	31.5	8.64	7.31	n.d	8.38	0.260
20140321pm	25	0.495	n.d	n.d	0.068	0.098	29.0	10.34	9.04	n.d	11.38	0.092
20140922	14	0.126	0.011	0.679	0.017	0.222	25.1	8.57	4.70	1.102	8.11	0.013
20141013	21	0.235	0.027	1.033	0.019	0.259	27.5	5.95	3.54	2.490	5.31	0.018
ABVA - VASYD			none	50	0.2			300		50		0.05

n.d = not detectable

Table 15. Results from elementary analysis of the Eastern outlet. (Time = days after emptying of tank)

Eastern (mg/L)	**Time**	**Al**	**Cd**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**P**	**Pb**	**S**	**Zn**
		mg/l	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	mg/l	mg/l
20140227	3	0.157	n.d	n.d	0.051	0.314	25.8	8.29	3.77	n.d	8.59	0.027
20140303	7	0.257	n.d	n.d	0.052	0.269	25.5	6.35	4.47	n.d	9.03	0.030
20140310	14	0.126	n.d	n.d	0.033	0.301	26.2	5.25	5.29	n.d	5.69	0.030
20140317am	21	0.089	n.d	n.d	0.031	0.205	25.2	5.15	4.17	n.d	6.05	0.025
20140317am	21	0.288	n.d	n.d	0.028	0.236	25.0	5.99	4.64	n.d	6.72	0.034
20140321pm	25	0.194	n.d	n.d	0.060	0.212	30.3	8.93	4.55	n.d	7.06	0.025
20140321pm	25	0.136	n.d	n.d	0.051	0.157	23.5	9.70	4.34	n.d	6.55	0.027
20140922	14	0.050	0.018	0.578	0.101	0.505	23.9	8.78	1.99	0.693	2.43	0.003
20141013	21	0.087	0.041	0.697	0.014	0.347	25.2	6.54	2.07	2.825	3.23	0.014
ABVA – VA SYD			none	50	0.2			300		50		0.05

n.d = not detectable

The elementary analysis of the outlet samples (Table 14-15) shows that the concentrations found are in general much lower than the demands in the VA SYD guideline. The zinc concentration is high for the Western outlet samples taken during spring and is higher than the allowed value for several samples. Another difference between the two systems is that aluminum is much higher in the Western outlet. An explanation could possibly be that the solubility of aluminum is pH-dependent. In general, the solubility will be increasing with falling pH below pH 6.3 (lowest solubility at pH 6). Aluminium can form a variety of hydroxo complexes, including aluminum hydroxide, ($Al(OH)_3(s)$, which is insoluble at pH ~6.5. The phosphorus in the Western outlet is in general higher than in the Eastern outlet. However, the phosphorus concentrations in the two tanks were about the same.

According to the guideline, there should be no cadmium in sewage from industries and other utilities, but household sewage is normally containing small amount of cadmium (VA SYD, 2010). In the analyzed samples, no cadmium could be detected during the spring, but in the autumn samples, a low concentration was seen for both systems, which can be explained by the fact that the detection limit was lowered. The same applies for chromium and lead.

3.2.6 Silver and fat

Fat in the outlet is of special interest due to concern for the condition of the sewers. Composite samples were analyzed for content of total fat, emulsified fat and separable fat. The results are shown in Table 16. Great variations in concentration can be seen, which is logical since the flow of water is varying. The requirements for wastewater quality to sewers that VA SYD puts on industries and other utilities is max 100 mg/L of separable fat. This value is exceeded only once, in the Western outlet. At that occasion the flow was very low, which might have influenced the sampling. Since all the other values are much lower it can be concluded that both tank systems are able to separate fat from water to a desirable level. The tank system also offers a possibility of reduction of fat coming from the ordinary kitchen sewage (not the waste that is ground), consisting of food scraps, sauce, drinks etc, that in other case would be going directly to the sewer system.

Table 16. Concentrations of fat and silver in outlet samples.

	Time	Emulsified fat	Total fat	Separable fat	Silver
Western outlet	days	mg/L	mg/L	mg/L	µg/l
03-03-2014	7	33	56	23	n.a.
10-03-2014	14	47	130	83	n.a.
17-03-2014	21	53	130	77	n.a.
21-03-2014*	25	52	250	200	n.a.
22-09-2014	14	15	78	63	0.11
13-10-2014	21	21	94	73	0.15
	Time	Emulsified fat	Total fat	Separable fat	Silver
Eastern outlet	days	mg/L	mg/L	mg/L	µg/l
03-03-2014	7	46	100	54	n.a.
10-03-2014	14	42	83	41	n.a.
17-03-2014	21	43	83	40	n.a.
21-03-2014	25	43	110	67	n.a.
22-09-2014	14	19	63	44	<0.1
13-10-2014	21	22	110	88	0.32

*Extremely low flow at the first sampling time the 21 March. n.a. = not analyzed

Silver was analyzed in the second sampling period (Sep-Oct) since it turned out that the installed waste disposers at Fullriggaren contains a BioShield layer, which included silver. The silver concentration in the four composite samples were <0.1-0.32 µg/L (see Table 16), which is low. The average concentration of Ag in incoming wastewater to Sjölunda WWTP during 2013 was 0.36 µg/L. The VA SYD guideline for Ag in sewage is < 50 µg/L, which is much higher.
The supplier of disposers, being aware of the problem, has also tested what concentrations of silver the disposers might yield by letting the disposers grind for 0, 3, 5 and 10 min (without waste – only recirculating water) and thereafter analyzing silver in the water (Dahlman & Nelson, 2013). All samples had Ag-concentrations below the detection limit, 0.05 µg/L. From this, it can be assumed that the silver concentration seen in the outlet at Fullriggaren is not coming from the disposers, but from the food waste or the other kitchen sewage.

3.2.7 Mass balances

Mass balances for dry matter, phosphorus and nitrogen were made up by combining the analysis results with key figures from literature when needed. One mass balance per sampling period was done; one for February-March and one for September-October. The mass balances (shown in the Table 17 below) are based on units of kg DM, g P or g N per household and day. The amount of food waste in the residual waste was taken from the waste composition analysis made in March 2014. The food waste in the tank represents the “collected” food waste from the system. The food waste in the outlet is the food waste that is leaving the system by passing the tank and thereafter going to the sewer net. The outlet mass was calculated by using the analyses of the outlet samples and combining them with the measured flow (using flow data from the Western tank outlet).

The total amount of food waste being ground by households and entering the FWD-system could not be measured in the studied area. Therefore, the neighboring area (with similar housings, but with paper bag system for collection of food waste) was investigated. The total amount of generated food waste was estimated as the sum of the food waste found in residual waste (based on data from waste composition analyses in the study area Fullriggaren) and the food waste separated in paper bags (based on waste composition analyses in the nearby area Flaggskepparen).

Table 17. Mass balances for DM, P and N for the two tank systems West and East during two sampling periods.

		West	**West**	**East**	**East**	
Mass balance		Feb-Mar	Sep-Oct	Feb-Mar	Sep-Oct	Used references for key figures
Food waste in residual waste	kg DM/hh/w	0.22	0.22	0.22	0.22	Biogas Syd, 2012
Food waste in tank	kg DM/hh/w	0.20	0.28	0.24	0.33	
Food waste in outlet	kg DM/hh/w	0.17	0.15	0.20	0.14	
OUT (rest + tank + outlet)	kg DM/hh/w	0.59	0.66	0.67	0.69	
IN (estimated from neighboring area)	kg DM/hh/w	0.60	0.60	0.60	0.60	Biogas Syd, 2012
Background DM	kg DM/hh/w	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4	Sundberg, 1995
P-balance						
Food waste in residual waste	g P/hh/w	0.50	0.50	0.50	0.50	Biogas Syd, 2012
Food waste in tank	g P/hh/w	0.54	1.1	0.58	1.1	
Food waste in outlet	g P/hh/w	5.0	2.8	3.0	1.6	
OUT (rest + tank + outlet)	g P/hh/w	6.1	4.4	4.4	3.1	
IN (estimated from neighboring area)	g P/hh/w	2.3	2.3	2.3	2.3	Vinnerås, 2006
Background P	g P/hh/w	*1.6-2.5*	*1-6-2.5*	*1.6-2.5*	*1.6-2.5*	Sundberg, 1995; Comber et al., 2013
N-balance						
Food waste in residual waste	g N/hh/w	5.2	5.2	5.2	5.2	Biogas Syd, 2012
Food waste in tank	g N/hh/w	6.5	8.5	8.1	11	
Food waste in outlet	g N/hh/w	34	29	18	13	
OUT (rest + tank + outlet)	g N/hh/w	45	43	31	29	
IN (estimated from neighboring area)	g N/hh/w	15	15	15	15	Biogas Syd, 2012
Background N	g N/hh/w	*17*	*17*	*17*	*17*	Sundberg, 1995

The efficiency of the system in terms of collected waste is between 0.20-0.33 kg DM/hh/w. The expected amount of generated food waste, which was estimated as the sum of food waste sorted out in paper bags and the food waste found in residual waste in the neighbouring area, is also low, 0.6 kg DM/hh/w. Thus, both the amount of separately collected food waste, as well as the total amount of generated food waste are well below the national average. The amount of food waste sorted out in apartments (with separate sorting of food waste; both plastic bags and paper bags) is around 1.4 kg waste/hh/w, and the total amount of food waste around 3 kg/hh/w, according to a study by Avfall Sverige (2011a and 2011 b). This corresponds to 0.48 and 1.02 kg DM/hh/week respectively (with a DM of 34%). A comparison of the food waste found in the residue with the food waste in the tank shows a rather high efficiency for the system, with the majority of the waste going to the waste disposers. This can be compared to the national average for food waste separately disposed of in paper or plastic bags (46% in multi-family dwellings, according to Avfall Sverige, 2011 b). The values are not fully comparable, since the value by Avfall Sverige will be lowered after pre-treatment. The waste collected in the tank is already pre-treated, so there will be no losses after the collection. As can be seen in the table, high amounts of both P and N are ending up in the outlet of the tank. This is logical because some of the P and N in the waste will be dissolved and can thereby not be hindered from leaving the tank.

There are large variations between the sampling periods in the mass of P and N ending up in different fractions. The variations are due to problems in getting representative samples, especially from the outlet. In the second sampling period triplicate samples of the outlet were taken out to increase the representativeness. The mass of P and N in the effluent are in general higher in the Western tank system, since the concentrations of P and N were higher there.

It can also be seen that the mass balances for dry matter (IN-OUT) are differing 1-13%, which can be explained by many factors e.g. the difficulty in sampling, flow measurements and precise analyses. Another explanation which is possible since IN<OUT in the cases where differences are high, is that the background kitchen waste that is poured into the sink (also without food waste disposer). e.g. sauce, drinks, food scraps and residues from dishing etc. is not included in the generated IN value. This could according to Sundberg (1995) correspond to about 14-23 g BOD/PE/d which could roughly be 0.2-0.4 kg DM/hh/week (assuming 1 g BOD = 1 g DM). The balances for phosphorus and nitrogen are differing quite much. Some of the reason must be the background level, which for both P and N could correspond to values that are even higher than the calculated amount in the generated food waste. The background levels from Sundberg (1995) are originating from data on grey water where the effect from detergents have been withdrawn and should be seen as maximum values. A british study (Comber et al., 2012) estimated phosphorus content in domestic food scraps and dish washing to 0.275 g P/PE/d, where the food scraps would correspond to 1.6 g P/hh/w and the dish washing would correspond to as much as 2.8 g P/hh/w. The P-content was high since UK did not have any restrictions on phosphorus in dish washer detergents at the time of the study. Phosphate content in automatic dish washer detergents will be restricted in the whole EU from 2017 (KemI, 2012)

3.2.8 Methane potential

The results of the biochemical methane potential (BMP) test are found in Figure 15 and Table 18 together with calculated theoretical methane potentials. The theoretical BMPs were calculated by the content of fat, protein and carbohydrate in the waste and their corresponding methane potentials (1014, 496 and 425 Nml CH_4/g VS). The test was stopped after 43 days of digestion. Both the waste from the Western and Eastern tanks gave high methane potentials and the degradation is fast. Almost all gas is produced during the first 10-15 days. However, the Eastern system's waste resulted in a substantially higher BMP, which also corresponded to a higher part of the theoretical value. About 90% of the theoretical value was achieved. The calculated theoretical potential did not differ much between the tanks (627 Nml CH_4/g VS – Western and 655 Nml CH_4/g VS – Eastern), which is logical since the organic content were similar. The difference in the experimental results, about 18%, was seen after 7 days and then continued throughout the remaining experimental period. Considering the content of the Western substrate, no logical explanation for the lower BMP is found. The metal content is not high enough to suspect inhibition and there is not a higher fat content (which could lead to overload) in the Western substrate.

The cellulose BMP was 350 Nml/g VS, corresponding to 84% of the theoretical value, which shows that the inoculum used was well-functioning, at least for carbohydrate rich substrates.

The methane potential for the reference slurry was 589 Nml CH4/ g VS according to Truedsson (2010). In other references the potential for food waste is usually lower, e.g. Carlsson & Uldal states 481 Nml CH4/g VS.

Table 18. Measured and calculated (from contents of fat, protein and carbohydrate) methane potentials for tank content from Western and Eastern system.

	Measured	**Calculated**	**Achieved**
Western (Nml CH_4/g VS)	492	627	78%
Eastern (Nml CH_4/g VS)	591	655	90%
Cellulose	350	415	84%

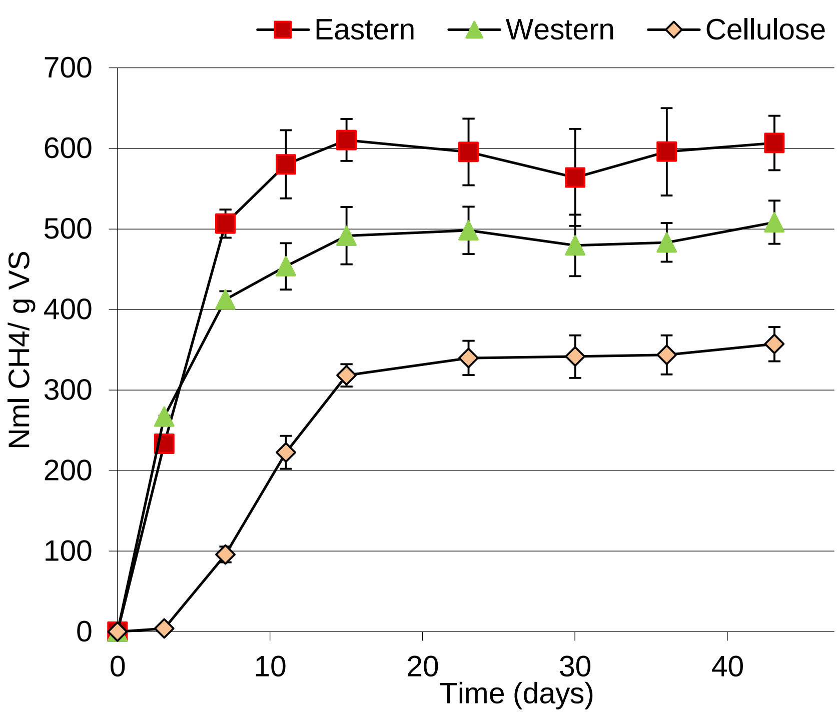


Figure 15. Average accumulated methane produced per amount of added organic matter (VS)

3.2.9 Summary and discussion about tank system differences

The design of the sedimentation tanks varied in the two systems installed in the case study are: the western system, with a smaller settling tank combined with a pre-settler and the larger settling tank in the eastern system. Some of the parameters differing between the two tank systems are summarized and discussed below.

- The dry matter concentration in the Eastern tank samples was higher, and eventhough the total volume was lower than for the Western tank this lead to a 20% higher yield in DM per household and week. The representativeness of the samples taken out for analysis is however important for this difference. It was seen that most of the waste in the Western system ends up in the pre-settler, which represents the majority of this system’s volume. This means that the DM-concentration in the pre-settler will have a big influence on the DM yield from the Western system. It was seen during sampling that the pre-settler contained a lot of waste, which could have reduced the possibility of taking representative samples out (sampling is also discussed in Chapter 3.2.1)
- pH was at all times lower in the Eastern tank content and also in the Eastern outlet. A low pH could be a result of a more extended hydrolysis, but the concentrations of dissolved COD, acetate and propionate were about the same in both systems, which does not support the theory. More investigations are needed to explain the differing pH.
- The Western tank content had generally higher zinc concentrations and the Eastern tank content had generally higher copper concentrations. The solubility for both these heavy metals is dependent on pH, but no variations between the systems outlet concentration were seen for either Zn or Cu.
- The temperature (measured in the first part of each system) was lower in the Eastern tank. The deepness of the pre-settler in the Western tank system (water depth 1600 mm and total depth 2680 mm) can make it less affected by the outdoor temperature.
- The meter registered a lower flow in the Eastern system. As is described in 3.2.4, it is probable that the measurement in this system was not reliable, since the flow meter worked out of range.
- Western outlet concentration of nitrogen and especially ammonium was higher indicating a more extensive hydrolysis in the tank leading to more nitrogen passing with the outlet. A low pH (<5.5 according to Veeken et al., 2000), as was seen in the Eastern tank, could inhibit hydrolysis. Aluminum, Zinc and phosphorus were also higher in concentration in the Western outlet.
- The methane potential was higher for the Eastern tank content even though the theoretical potential was about the same as for the Western tank content. A hypothesis could be that the organic matter in the Eastern system could be more degradable, but more tests are recommended to verify this.

3.3 System analysis

As seen in Figure 16**,** upstream emissions of greenhouse gases (GHG) are higher in the FWD-system compared to the reference system. This is primarily an effect of the use of electricity in food waste grinders in the FWD-system (included in “collection” in Figure 16). However, this is compensated by a higher output of biogas and substitution of mineral fertilizers, resulting in higher overall avoidance of GHG-emissions in the FWD-system.

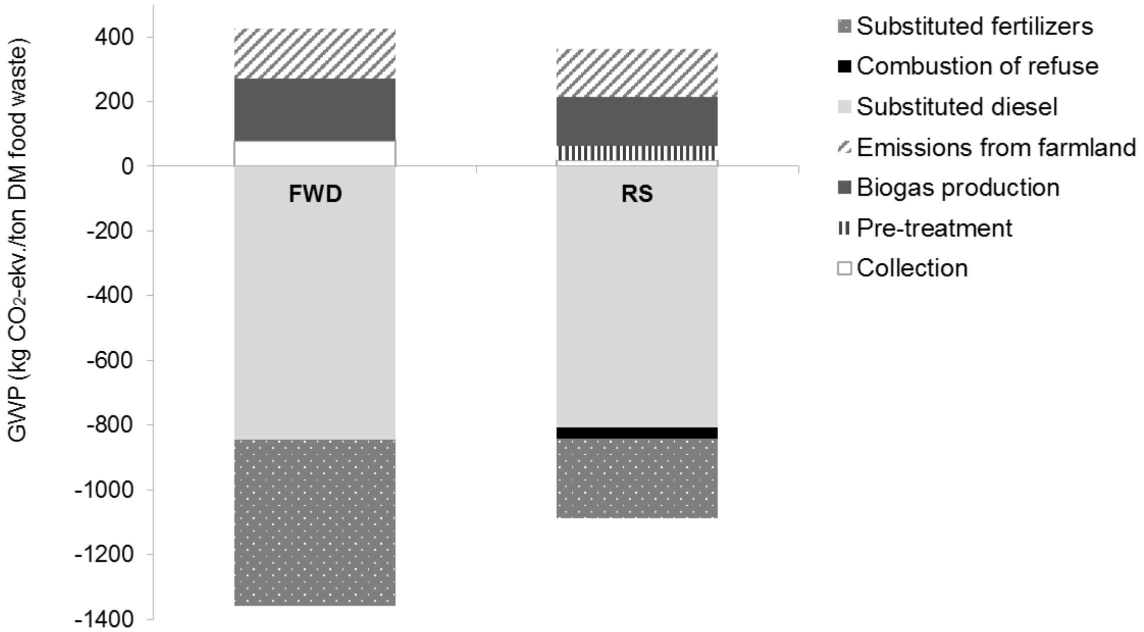


Figure 16. Overall emissions of GHG from compared systems. FWD = Food waste disposer system. RS = Reference system. The category “Collection” includes material and energy needed for disposal.

Emissions from storage and farmland application of digestate and emissions of methane from anaerobic digestion and upgrading (included in “biogas production” in Figure 16) are the processes with highest contribution to GHG-emissions from both systems. These were followed by emissions related to energy use in grinding of food waste in the FWD-system. A higher concentration of nitrogen in food waste collected from the FWD-system (based on data presented in section 3.2.7), compared to previous analyses of food waste collected in paper bags (presented in Appendix 3), increases the avoidance of GHG-emissions from use of digestate on farmland in the FWD-system.

Avoided GHG-emissions were calculated to -933kg CO_2-eq./ton DM in the FWD-system and -727kg CO_2-eq./ton DM in the reference system. Results can be compared to Bernstad (2012), a previous LCA of tank connected FWD-systems. In the previous study, avoided emissions of GHG from the FWD-system were around 30% lower compared to the present study. This is primarily a result of an assumed lower electricity use food waste grinders, higher substitution rate of mineral fertilizers through nutrients in digestate and an assumed higher biogas production per kg food waste disposed of in the present study compared to the previous. In addition, processes related to transport and spreading of digestate were excluded in the present study.

In the FWD-system, the electricity needed for grinding of food waste (included in the category “collection” in Figure 17) causes a high input of primary energy to the system. In the reference system, the amount of primary energy needed for production of paper bags and vessels as well as the collection of food waste in two-compartment trucks, is much lower. This is the main reason behind the energy balance being advantageous for the reference system compared to the FWD-system (-12 951 MJ/ton DM compared to -12 079 MJ/ton DM) (Figure 17).

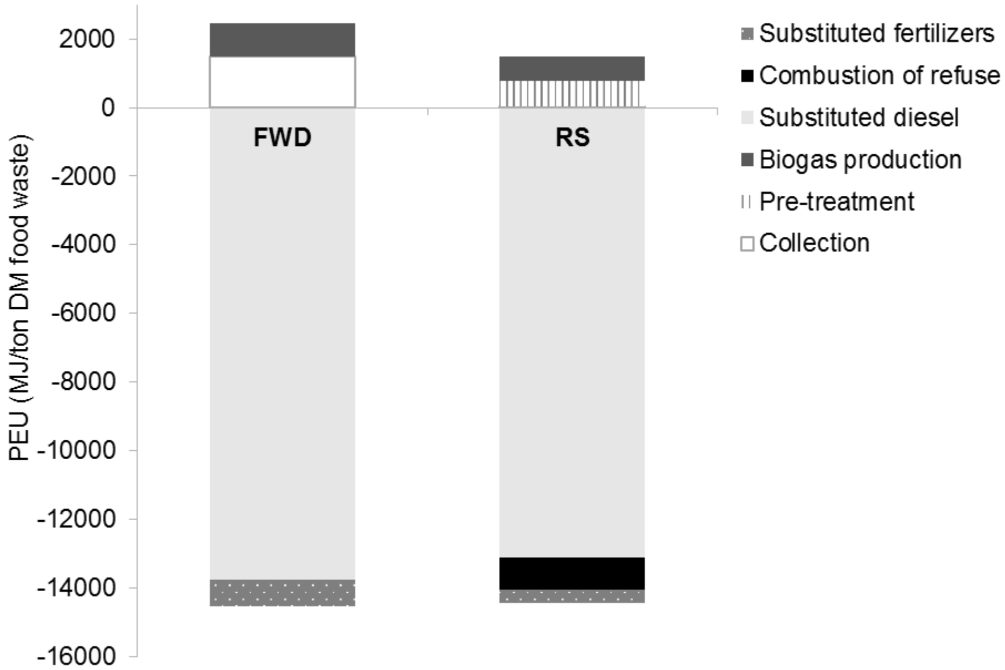


Figure 17. Energy balance (as primary energy use, PEU) in compared systems. FWD = Food waste disposer system. RS = Reference system. The category "Collection" includes material and energy needed for disposal.

3.3.1 Uncertainty and sensitivity analyses

The impact from changes in selection of input data and assumptions made in the performed LCA, was investigated through uncertainty and sensitivity analyses. Uncertainty analyses were performed in order to investigate the effect of changes in used input data on the overall results of the study. Processes selected for investigation were such where large variations can be seen in the literature, or where input data used in the study was based on assumptions. Input values were adjusted either within a range presented in literature, or as a change in percent related to currently used value. Sensitivity analyses were performed to investigate the effect of changes in modeling of the two systems. Data used in the analyses are presented in (Table 19).

Table 19. Summary of performed sensitivity analyses. FWD = Food waste disposer system. RS = Reference system.

Scenario	Process	Current value	Investigated values
A	Electricity used in FWD	158 kWh/ton DM	+/- 50%
B	Reduced losses of organic matter, N and P from tank	See section 3.2.7.	+/- 20%
C	Reduced losses in pre-treatment	27% (mass)	+/- 50%
D	Degradation ratio of VS in food waste in RS	80% of VS	85% of VS

E	Decreased concentration of N-tot in food waste sludge	33g/kg DM	20g/kg DM
F	GHG-emissions from N-fertilizer production	15.5 kg CO_2-eq./kg N	2.9 kg CO_2-eq./kg N
G	Use of diesel in collection vehicles	FWD: 54 kWh biogas RS: 9.4 kWh biogas	FWD: 54 kWh diesel RS: 9.4 kWh diesel
H	Use of plastic bags for collection of food waste in RS	18.2 kg CO_2-eq./ton food waste	79.8 kg CO_2-eq./ton (PE[1]) 16.8 kg CO_2-eq./ton (PB[2])
I	Excluding impacts from incineration of refuse from pre-treatment.	Included	Excluded

[1] Polyethylene (High density).

[2] Bio-plastics.

Results from uncertainty and sensitivity analyses are presented in Figure 18. In the following, impacts from analyses are commented upon in relation to GWP and PEU, with focus on potential changes in the hierarchy between compared collection systems.

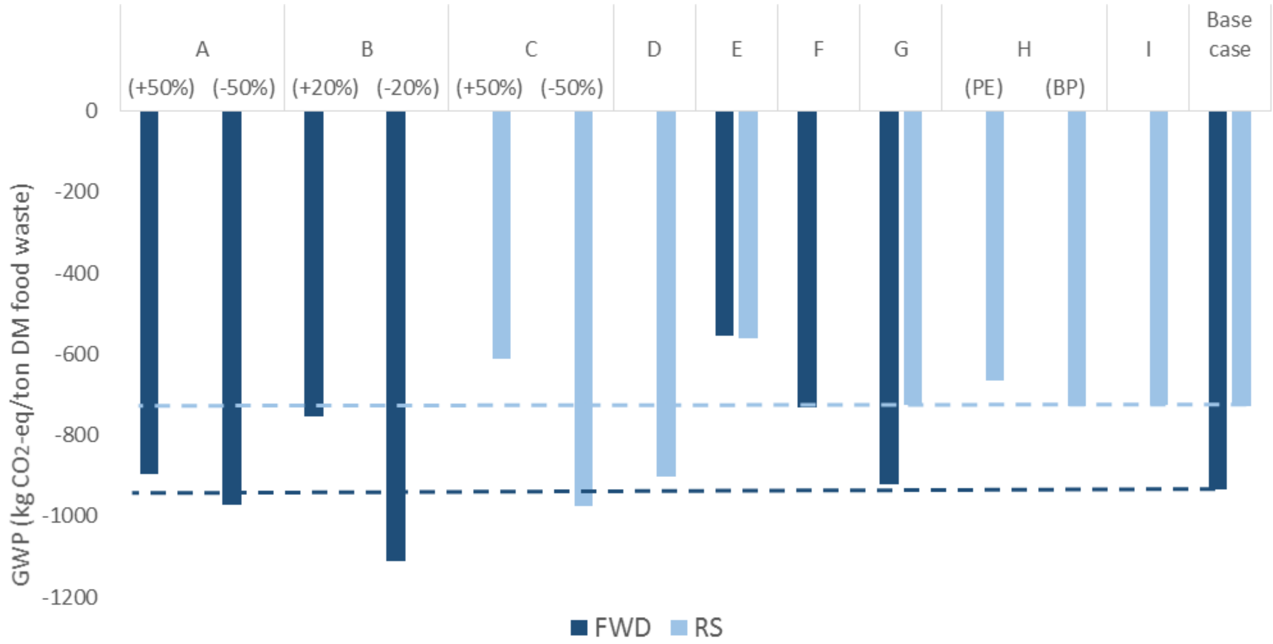


Figure 18. GWP from FWD and RS systems; base case and results from performed uncertainty and sensitivity analyses (absolute numbers). Dotted lines represent GHG-emissions from FWD and RS systems in the base case in order to facilitate comparisons.

A: The amount of electricity used in the grinding of food waste is largely dependent on user behavior. The use vary between households, as well as between individuals within the same household. To examine the effect of this on the results, a sensitivity analysis in which usage increases or decreases by 50% compared with the assumption in the base case. The influence of this change in relation to GHG-emissions from the systems is limited, and has no impact on ranking between the systems.

B: Biogas production from food waste collected in the FWD-system was in the base case calculated as the amount of biogas produced per ton VS food waste sludge, minus the fraction of VS lost as effluent. The amount of mineral fertilizers (N and P) substituted by nutrients in produced digestate was assessed based on analyses of nutrient content in collected food waste sludge. In all cases, substantial amounts of these substances are found in tank effluent (> 20%, based on analyses of organic matter, N and P). Due to the high influence from substituted diesel and mineral N-fertilizers on the overall emissions of GHG from the FWD-system, changes in assumed losses of organic matter and nutrients from the system has a large impact on the results. In fact, increasing and reducing losses with 20% will increase and reduce overall GHG-emissions from the system with almost the same percentage (19% in both cases). Decreasing losses with 20% would make FWD preferable to the RS in relation to use of primary energy, while increasing losses with 20% not would change the hierarchy between the systems in relation to GWP, but decrease the previous difference between the systems largely.

C: Losses in mechanical pre-treatment of food waste collected in paper bags has a large impact on GHG-emissions from the reference system. Decreasing losses with 50% (i.e. assuming losses equal to 14% (mass) of DM), changes ranking of systems in relation to GWP, while increasing losses with 50% (i.e. assuming losses equal to 41% (mass) of DM), makes FWD preferable in relation to use of primary energy use.

D: Based on results from batch methane potential tests presented in this study, the degradation ratio of VS from FWD was assumed to 90% in the base case, based on results from the present work. In the reference system, however, the degradation ratio was assumed to 80% of VS, based on Davidsson et al. (2007). However, in Kjerstadius et al. (2012), the degradation rate from batch methane potential tests of food waste collected in paper bags was determined to 90%. Results from an uncertainty analysis where the data on degradation rate from Kjerstadius et al. (2012) was used in the reference system, show that this not would change the hierarchy between the systems.

E: Decreased emissions of GHG-emissions due to technological advances in N-fertilizer production will have a larger effect on the FWD-system, as a larger fraction of overall avoided GHG-emissions from this system is related to fertilizer substitution. Thus, drastically decreased GHG-emissions from N-fertilizer production in the future could make the two systems equivalent in relation to GHG-emissions.

F: According to analyses of food waste sludge presented in this study, the concentration of N-tot in this waste is high, compared to previous analyses of food waste collected in systems similar to the reference system. This is probably related to background N-tot in the FWD-system (see section 3.2.7). Thus, it can be questioned to what extent these nutrients should credit the FWD-system. In a sensitivity analysis, it was assumed that the concentration of N-tot was the same in both systems (20g/kg DM, based on analyses of food waste separately collected in paper bags (Davidsson 2007)). As the substitution of mineral N-fertilizers was responsible for a large part of the avoided GHG-emissions from the FWD-system, this change could cause a large decrease in overall GHG-avoidance from this system (-22%) and make the two systems equivalent in relation to GHG-emissions.

G: The fuel use in collection of separately collected food waste has a limited impact in both investigated systems. Thus, a change from biogas to diesel in collection vehicles has a limited impact on overall emissions of GHG in relation to both the FWD-system and the reference system (1.1 and 0.3% respectively).

H: In the sensitivity analysis, two different types of plastic bags were used for separate collection of food waste in the reference system; plastic bags made from virgin plastic (HDPE) with production region Europe, and bio-plastic bags based on corn starch and sunflower oil, with an addition of 30% (mass) dolomite, produced in Italy (Alexandersson et al., 2013). GHG-emissions related to use of plastic bags also includes incineration of bags after separation from food waste in the pre-treatment process. Despite of the large variations in GHG-emissions from production of each unit of bag (see Appendix 3), impacts on GHG-emissions from the reference system as a whole were small and did not cause changes in ranking between the systems.

I: System boundaries were in the LCA set so that subsequent treatment of refuse separated through pre-treatment of food waste collected in paper bags was considered. At the same time, organic matter and nutrients lost from the separation tank to the sewer in the FWD-system, were not addressed. However, results show that exclusion of impacts related to treatment of refuse after pre-treatment in the reference system not would change the hierarchy between the systems.

3.3.2 Discussion system analysis

Systems emissions of greenhouse gases from collection and treatment of 1 ton of food waste (dry matter), are according to the performed carbon footprint lower from the FWD-system compared to the reference system, where food waste is separately collected in paper bags by households. The main reasons for this is a higher substitution of diesel and mineral nitrogen fertilizer in the FWD-system compared to the reference system. However, according to performed uncertainty analyses, results are not entirely robust in relation to changes of some of the values used as input data in the study, which affects methane production and nutrient recovery from the systems.

Thus, decreasing losses of organic matter in pre-treatment of food waste collected in paper bags or increased losses of organic matter and nutrients from the FWD-system could make compared systems equivalent and in some cases even change the hierarchy in relation to GHG-emissions. This could also be the results of a decreased recovery of N-fertilizers from FWD-system or decreased GHG-emissions from production of mineral fertilizers. Although the FWD-system is more beneficial in relation to GHG-emissions under conditions in the base case, relatively small changes in input data can have impacts on results that would change overall conclusions from the LCA. This should be held in mind in the interpretation of results gained in the study.

Also, due to the many questions still remaining regarding the impacts of an increased amount of nutrients and organic matter to the sewage system, the later treatment of effluent from the FWD-system, as well as treatment of wastewater from kitchen sinks in the reference system, was not included in the assessment. In future work, it would be of relevance to monitor these flows and include the environmental impacts further down the system.

4. Conclusions

Waste composition analysis do not give any evidence on differences in food waste separation behavior between areas with food waste disposer (FWD) and separation of food waste in paper bags.

The efficiency of the FWD-system in terms of collected waste from the tanks is between 0.20-0.33 kg DM/hh/w, which is rather low. However, the estimated amount of generated food waste is also low, 0.6 kg DM/hh/w. This means that 33-55% of the food waste can be collected and transported directly to a biogas plant. The waste collected in the tank is already pre-treated, so there will be no losses after the collection. The rest of the food waste is either found in the residual waste (37%) or passes the tank and goes with the outlet to the sewer (23-33%). It should be noted that the sum of dry matter in the tank, outlet and residual waste is higher than the expected food waste into the system. The difference is partly explained by the ordinary kitchen sewage like food scraps, drinks, sauce etc.

The amount of collected waste from the tanks and the relatively high dry matter content (3-5%) indicates that the kitchen grinders are used and that the separation tanks are able to thicken the waste substantially.

The organic content of the collected waste is high, around 95% of the dry matter, indicating a high potential for biogas production. The methane potential tests also showed that there is a high potential. Almost 90% of the theoretical methane potential was achieved for the waste from the Eastern system and 78% for the Western system. More than 90% of the gas is produced during the first 11 days, indicating a fast degradation.

The elementary analysis of the tank content showed that the metal content is mostly low, but for some samples the copper and zinc content was over the limit value for re-use on farmland. The cadmium content is low and below the current limits for sludge or digestate to farmland. The ratio between cadmium and phosphorus is between 30-47 mg Cd/kg P, which is on the limit or higher than the limit in the REVAQ system for sewage sludge. This relatively high value is an effect of the low phosphorus content in food waste and not due to the FWD-system.

The quality of the outlet is indicating a satisfactory separation of particulate organic matter and fat. A portion of the organic content and nutrients from the waste or the kitchen wastewater is in dissolved form and cannot be caught in the tank but is led to the sewage via the outlet. Concerning specific parameters analyzed in the outlet it can be seen that the metal content is very low and that most other parameters are lower in concentration than the allowed value for wastewater from industries and utilities to the sewer net. The suspended solids are higher than the allowed value but still lower than what is found in the inlet to the wastewater treatment plant Sjölunda in Malmö. The pH is rather low (5.6-6.4) which can increase the risk of corrosion in sewer pipes. However the pH can be expected to increase when the outlet is mixed up with sewage from the bathrooms.

No indications of elevated silver concentrations in either tank content or outlet water were seen although the grinders include a bioshield layer, which could lead to silver release.

Three methods for taking samples from the tank were compared. The Winckler method was considered most appropriate for this project since it is simple, it does not demand a vacuum truck, samples can be taken out for evaluation of the development between two emptying periods and it gives information about the function of each compartment.

When comparing the two different tank systems installed some differences can be seen. The Eastern system, with a larger separation tank, has a higher DM/household and week and also higher methane potential/VS. This indicates that the Eastern system is more effective from a biogas production perspective, however more tests are needed to verify this.

A carbon footprint of the FWD-system shows that this can be preferable in relation to emissions of greenhouse gases, compared to a reference system with separate collection of household food waste in paper bags. The main reasons for this are a higher substitution of diesel and mineral nitrogen fertilizer in the FWD-system. However, decreased losses of organic matter in mechanical pre-treatment of food waste collected in paper bags or decreased substitution of mineral nitrogen fertilizers with high environmental impacts in the FWD-system, could make compared systems equivalent in relation to GHG-emissions, or even change the hierarchy. Thus, relatively small changes in values affecting methane production and nutrient recovery can have impacts on results that would alter overall conclusions from the carbon footprint study. This should be held in mind in the interpretation of results gained in the study.

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Appendix 1. Characterization factors

Global warming potential (GWP) balance from compared system is based on characterization factors presented in Table 1.

Table 1. The characterization factors used in the study according to the IPCC 2007 (EcoinventCenter, 2010).

Emission	kg CO_2-ekv./kg
CO_2 (fossil origin)	1
CO_2 (biological origin)	0
CH_4	25
N_2O	298

The energy balance is made on basis of primary energy conversion factors listed in Table 2.

Table 2. Conversion factors used in the study, according to Börjesson et al. (2010).

Primary Energy Factor, electricity	2.2
Primary energy factor, heat	1
Primary energy factor, fuel	1.18

This perspective implies that the use of 1kWh of electricity produces a strain in the energy balance corresponding to the use of 2.2kWh of heat.

Appendix 2. Substitution of mineral fertilizers

The amount of mineral fertilizers substituted by digestate from anaerobic digestion of food wate has previously been assumed to between 30% (la Cour Jansen et al., 2007) and 100% (Hirati, 2000; Aye and Widjaya, 2005; Lantz, 2009; Khoo et al., 2010). How much of the nutrients in the digestate that is plant available and thus can be considered to substitute chemical fertilizers partly depend on factors such as when digestate is applied on farmland and type of crops grown in the field (Jönsson, 2013). In the present study, we assume that digestate is applied on crop with longer growth period, which increases the utilisation rate of nitrogen in digestate, according to previous studies up to 122-144% compared to mineral fertilizers (Christensson and Blohmé, 2002). A substitution rate of 100% was seen in Karlsson (1999), and is used in the present study. The replacement rate of mineral phosphorus and potassium fertilizers is, based on previous studies, assumed to 100% (Aye and Widjaya, 2005; Lantz, 2009; Khoo et al., 2010; Börjesson and Berglund, 2007). Data on emissions and energy use for the production of mineral fertilizers were collected from Börjesson and Berglund (2007).

Production of mineral fertilizers can lead to large emissions of greenhouse gases (Jenssen and Kongshaug, 2003). This applies mainly to the production of synthetic nitrogen, which is energy-intensive and where nitrous oxide is produced as a waste product. Catalytic cleaning of nitrous oxide can however reduce nitrous oxide emissions by 70-90% (Jenssen and Kongshaug, 2003). The Swedish fertilizer market is dominated by Yara AB, which in 2009 accounted for 60-80% of the mineral fertilizers used in Sweden (Stadskontoret, 2010). Yara has in recent years introduced catalytic reduction of nitrous oxide in a large proportion of their production, and according to Yara (2013) total GHG-emissions from production of ammonium nitrate fertilizers sold in Sweden are 55% of the level adopted by Jenssen and Kongshaug and 19% of the levels presented by Börjesson and Berglund (2007). Based on the same logic that is used around the assumption about the environmental impact of the electricity that is substituted by the system is assumed here that the most environmentally damaging chemical fertilizers is being replaced at the margin, while the use of the values Yara AB (2013) presents examined in a sensitivity analysis.

Appendix 3. Lifecycle inventory data used in the LCA

Table 1. Input data used in the LCA.

General	**Value**	**Unit**	**Reference**
Number of households in Fullriggaren	614	apartments	Bissmont, 2014
Density methane	0.716	g/m3	
Lower heating value (LHV) methane	9.97	kWh/Nm^3	
LHV methane	35.9	MJ/Nm^3	
Substituted diesel (production and use)	0.073	kg CO_2/MJ	Svenska Petroleum och Biodrivemedel Institutet, 2014
Combustion of biogas in vehicle	0.003	kg CO_2/MJ	Fruergaard and Astrup, 2011
Energy	**GWP**	**Unit**	**Reference**
Electricity production (future marginal, natural gas)	0.474	kg CO_2-eq/kWh	Gode et al., 2011
Thermal energy average Sweden	0.089	kg CO_2-eq/kWh	Gode et al., 2011
Primary energy factor electricity	2.2		Börjesson and Berglund, 2007
Primary energy factor thermal energy	1		Börjesson and Berglund, 2007
Primary energy factor car fuel	1.18		Börjesson and Berglund, 2007
FWD-system			
kg DM food waste/household, week	0.33	kg DM/hh, week	This study
VS in food waste sludge	95%	of TS	This study
Energy use in food waste grinding	0.16	kWh/kg DM	Davidsson et al., 2011
Water use in grinding	4.2	L/kg DM	Davidsson et al., 2011
Energy use related to water production	0.0002	kWh/kg water	EcoInvent 3.0
GWP related to water production	0.063	kg CO_2/kg water	EcoInvent 3.0
kg food waste sludge per collection	810	kg DM	This study
Energy use in tank vehicle	118	MJ/collection round	Jönsson, 2014

Methane production from food waste FWD	581	m^3 CH_4/ton VS	This study
Degradation factor	90%	of VS	This study
Reference system			
kg food waste/household, week	0.94	kg/hh, week	
kg DM food waste/household, week	0.33	kg TS/hh, week	
kg food waste/paper bag	3	kg/bag	Vucicevic et al., 2012
kg paper bag/ton food waste	5.2	kg	Bissmont, 2014
kg paper bag/ton TS food waste	14.9	kg	
kg plastic vessel/ton TS food waste	0.004	kg	3 year life time (assumed)
Material loss in pre-treatment	27	% mass	Truedsson, 2010
Loss of nutrients (N, P and K) in pre-treatment	27	% mass	Assumed
Loss of VS in pre-treatment	27	% mass	Truedsson, 2010
Energy use in pre-treatment	19.4	kWh/ton food waste	Truedsson, 2010
Electricity input in incineration	73	kWh/ton DM	Jung, 2010
Fraction electricity in incineration of residues	0.2		Sysav, 2009
Fraction heat in incineration of residues	0.8		Sysav, 2009
LHW paperbags	13.7	MJ	Easewaste, 2010
LHW food waste refuse	1083	MJ	Truedsson, 2010
DM in food waste	35%	% mass	Avfall Sverige, 2011
VS in food waste after pre-treatment	91%	of TS	Truedsson, 2010
Methane use in waste collection vehicle	8.20	kWh/km	Rehnlund, 2010
Assumed distance	15	km (return)	
Capacity	6	ton	Rehnlund, 2010
Fraction food waste per two compartment vehicle	16%	%	Bissmont, 2014
Methane production from food waste FWD	589	m^3 CH_4/ton VS	Truedsson et al. 2010
Degradation factor	80%	of VS	Davidsson et al. 2007

Nutrient content food waste collected in paper bags	Value	Unit	Reference
N-tot	14.6	g/kg TS	Davidsson et al. 2007
P-tot	2.8	g/kg TS	Davidsson et al. 2007
K	7.3	g/kg TS	Davidsson et al. 2007
C	304	g/kg TS	Davidsson et al. 2007
Use on-land emissions from digestate	Value	Unit	Reference
Emissions of CH_4 from storage of digestate	10	% of residual CH_4 production	Lantz et al. 2009
Emissions of NH_3 from storage of digestate	7	% of N-content	Lantz et al. 2009
Emissions of NH_3 from farmland application	5	% of NH_3 content	Lantz et al. 2009
Emissions of NO_3- from farmland application	9.25	% more than chemical fertilizers	Lantz et al. 2009
Indirect emissions of N_2O from farmland application	1	% of NH_3 evaporation	Lantz et al. 2009
Direct N_2O emissions from farmland application	1.2	% of N-tot	Lantz et al. 2009
Biogas production	Value	Unit	Reference
Electricity input in digestion of food waste	17	kWh/ton wet waste	Waste Refinery, 2013
Heat input in digestion of food waste	57	kWh/ton wet waste	Waste Refinery, 2013
Emissions from digestion of food waste	1.0%	of produced CH_4	SGC, 2013
Emissions from upgrading of biogas	0.8%	of upgraded CH_4	SGC, 2013

Grinding of food waste in FWD-system
Electricity and water consumption in households: Electricity consumption in grinders was estimated based on installed power (373 W/s) and the assumption that the mills used 60 s per household and day. Assuming that 0.25 kg dry food waste is ground per household and week, results in an energy consumption of 8.7 kWh/kg DS. Extra water use in kitchen sinks was estimated to 4.2 L/kg DS, based on Davidsson et al. (2011). However, several previous studies have not been able to detect any increase in household water-use due to installation of food waste grinders (Evans, 2012).

Use of collection material

Table 4. Input data used in sensitivity analysis with use of plastic and bio-plastic bag for collection of food waste in reference system.

Type	Production (kg CO_2-eq./bag)	Combustion (kg CO_2-eq./bag)	Total (kg CO_2-eq./bag)	Weight (g/bag)	kg CO_2-eq./kg bag	kg bag /FU	kg CO_2-eq. /FU
Paper bag[1]	11	-1	10	15.6	0.64	1.82	18.2
Bio-plastic bag[2]	12	6	18	8	2.25	0.93	16.8
HDPE[2]	31	26	57	12	4.75	1.40	79.8

[1] Bissmont, 2014.
[2] Alexandersson et al., 2013.