Food waste in Beijing

- life cycle assessment approach to estimating the environmental impact and resource utilization of various alternatives for food waste treatment in Beijing

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Abstract

Around the world, the treatment of food waste is a major administrative and environmental problem throughout the food supply chain. Beijing, as any other mega city, is facing vast issues of sustainable food waste treatment in addition to efforts for food waste reduction. Presently the majority of Beijing's food waste is treated together with the mixed residual waste in landfills (53%) and incinerators (43%) with only 4.3 % of the food waste being organically recycled. This despite the majority of Beijing's municipal solid waste being food waste. Beijing is quickly developing its incineration capacity due to the volume reduction and energy recovery potential.

Treating the food waste with anaerobic digestion could provide an alternative waste-to-energy method which includes resource recycling. Demands for the by-products of anaerobic digestion appear to increase as demand for natural gas and demand for organic produce is predicted to increase in China.

The software WAMPS (Waste Management Planning System) is used to investigate six scenarios for the various possibilities of future food waste treatment in Beijing using a life cycle perspective. The scenarios are modelled after a goal scenario where 50% of the food waste is recycled and a half way scenarios between present situation and the goal. The study concludes that incineration is the most environmentally friendly alternative but foremost shows a lot of room for improvement for the present management system. The results are largely influenced by the coal based electricity production in China which causes severe environmental problems and offers great environmental advantages when reduced and replaced with cleaner electricity. The case study does not consider the sustainable use of resources, only eutrophication, acidification, greenhouse gas emissions, and photo oxidant formation.

Keywords

Food waste management, Anaerobic digestion, Life cycle perspective, Beijing, China, WAMPS, Waste management planning system

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The research for this report has been done as a minor contribution to the REFRESH project [31] in China in collaboration with IVL Swedish Research Institute's [22] Beijing representation office. REFRESH is an initiative with a mission to help its participators (China and the EU) reach the Sustainable development goal 12.3, that by 2020 have halved the food waste per capita in the world [40].

Contents

1 Abreviations

CNG – Compressed Natural Gas

IVL – Swedish Institute for Water and Air Pollution research

(Swedish: Institutet för Vatten och Luftvårdsforskning)

LCA – Life cycle analysis

PM – Particulate Matter

REFRESH – Resource Efficient Food and dRink for the Entire Supply cHain

WAMPS – Waste Management Planning System

2 Introduction

China, the world's most populous country, home to 19% of the world's urbanized population [3] and the producer of 15% of the world's urban waste [4], faces vast challenges regarding the sustainability of its municipal solid waste management. Beijing, the capital of China, and home to more than 21 million people [34] has a municipal solid waste mass increase of 2.6% per year [25] due to both urbanization and increasing waste production per capita. Following the pattern of emerging economies [25], the food waste fraction of the municipal solid waste is higher in Beijing than it is in western industrialized countries. The fraction of food waste in Beijing's municipal solid waste has gone from 24% 1990 to 48% in 2003 [50] reaching 54% in 2012 [55].

Though first and foremost aiming to reduce the waste volume [46], for now, the clear majority of the waste ends up in overburdened landfills, where food waste produces methane - a greenhouse gas 25 times as potent as carbon dioxide [19]. Only a small fraction of Beijing's landfills have facilities for landfill gas collection [58]. Efficient and sustainable municipal solid waste management is necessary as disposal methods affect both the natural environment and the health of Beijing's residents.

2.1 Purpose of Study

This report aims to study the environmental impact and resource utilization of various methods for treatment of food waste in Beijing. Current methods of food waste treatment are compared with modelled future scenarios in order to understand possible benefits of a system with increased anaerobic digestion, incineration and/or composting. This report will briefly review other reports on the subject as well as contribute with a small case study. As a part of IVL Swedish research institute's contribution to the REFRESH project in China, this report aims to add to the ongoing Chinese path to reach the United Nations' sustainability goal 12.3.

2.2 Formulation of questions

The questions this study intends to answer are as follows:

- How does the current situation for food waste collection, infrastructure and food waste treatment facilities look in Beijing?
- What is the current circulation of the organic waste treatment bi-products, biogas and bio fertilizer?
- What is the environmental impact and resource utilization impact of food waste in Beijing at present time?
- Which are the preferable methods for food waste treatment in Beijing?

2.3 Limitations

The reasons for the focus of this study are many; Beijing is the capital of the nation with world biggest waste generation, China is the worlds second largest economy (and likely to eventually become the world largest) and an immensely powerful country, both regarding soft and hard power. Numerous developing countries are following the Chinese model of economic development, increasing the importance for of China's sustainable development as it serves as a role model. This study limits itself to looking at the environmental effects of the full composition of municipal solid waste since it is difficult to isolate the environmental emissions related to the treatment of exclusively food waste, which is presently treated together with the mixed residual waste. The main focus remains of food waste since food waste is a big issue in all parts of the food supply chain. Thus food waste reduction is addressed in the United Nations sustainable development goals. IVL Swedish reaserch institute has earlier conducted research focused on food waste reduction and waste in earlier stages of the food supply chain in China; leaving the end of the supply chain to be the focus of this study. The study is limited to discussing the environmental impacts of waste treatment in Beijing and does not further discuss economics factors which would be involved in policy making etc.

2.4 Method

The study is conducted both as a literature study of municipal solid waste treatment methods and a small review study to gain understanding of the food waste treatment in Chinese mega-cities. A small case study to provide a life cycle perspective on present and modeled future scenarios has also been conducted using the municipal solid waste management tool WAMPS (Waste Management Planning System), developed by IVL Swedish research institute. Data for the case study has been collected from literature. Parameters from Swedish municipal solid waste is presented in the study in order to compare the conditions of municipal solid waste in a developed western country to the situation in Beijing.

3 Literature studies

3.1 Municipal solid waste management in Beijing

Every year 7,9 Mtons of municipal solid waste is produced and collected in Beijing [35]. This means that 1,0 kg of municipal solid waste is produced in Beijing per capita per day, which could be compared to the 1,3 kg per capita per day in Sweden [39]. The daily collection and transporting of this waste is contracted to the Beijing Environment Sanitation Engineering Group Company since 10 years [43]. A small waste management fee is charged to residents of Beijing but studies show that the willingness to pay is still very low [50].

The collected waste is taken either straight to a landfill or to a transit centre from which it is brought to one of the 22 treatment facilities including landfills, incinerators and composts around the city [25]. The general flow of the municipal solid waste can be seen in Figure 1. 2012 fractions of each treatment method in Beijing and Sweden (for comparison) is displayed in Table 1.

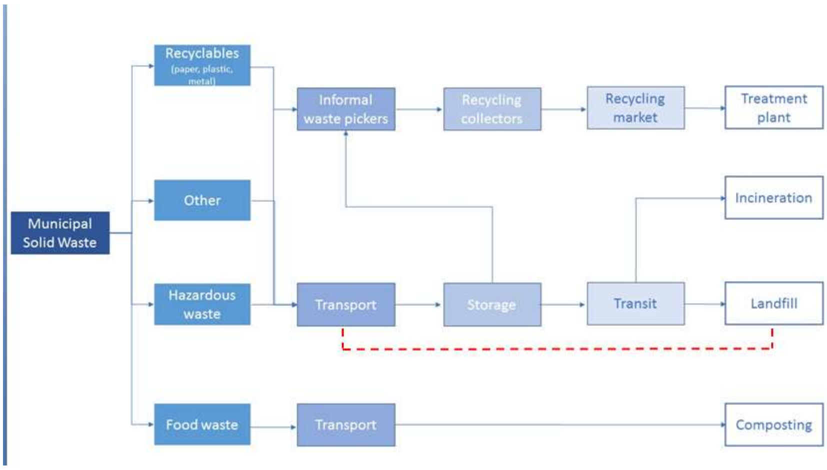


Figure 1: This flowchart shows the present treatment system for Beijing's municipal solid waste and was produced by QiLu [58]. The red, dotted, line has been added since others [25] report that not all waste goes through transit centers.

The waste composition in Beijing has changed drastically over the last three decades. From consisting of a large part of ashes in the early 90's, to the fast increase of plastic and paper waste during the 90's to a majority being food waste from 1995 until today [50][25]. Present municipal solid waste composition in Beijing is displayed in Table 2.

Table 1: Present treatment methods of Beijing's and Sweden's municipal solid waste in mass percentage. This is the waste dealt with by the official channels, which is why material recycling for Beijing is zero [**5**] [56] [57] [39].

Treatment method	**Beijing(%)**	**Sweden(%)**
Organic recycling	2.3	15.5
Incineration	43.0	48.6
Landfill	54.7	0.8
Material recycling	0	35.1
Total	100	100

Table 2: Composition of municipal solid waste in Beijing 2012 [55].

Material	**Mass%**
Food waste	54.0
Plastic	18.6
Paper	17.6
Wood	3.08
Soil and dust	2.15
Glass	2.07
Textile	1.55
Brick	0.57
Metal	0.26
Total	99.9

As the composition of the waste has changed, so has the calorific value which has increased from 2,7 MJ/kg in 1990 [50] to 5,7 MJ/kg in 2012. This opens up for possibilities of incineration but is still low compared to European values where for example Swiss municipal solid waste has a calorific value at 12,5 MJ/kg.

Xiao Yi et al. [50] estimates the total source separation, i.e. separation of different kinds of waste before it is collected, in the city to be around 15%. This number is largely achieved by the between 150 000 to 180 000 informal waste pickers in Beijing who collect valuable materials such as plastic, paper and metal from the solid waste all over the metropolitan area [13]. This waste ends up at informal recyclers, its weight is not included in the presented weight of collected municipal solid waste and is estimated to represent around 8-10% of the actual generated amount of waste [15]. This report will concern the collected part of the municipal solid waste and will not consider the non-collected remains in its calculations. The waste collected and treated by informal channels is not included in Table 1 and 2. For an overview of Beijing's waste management system, see Figure 1. Beijing's solid waste management system is changing rapidly including new technologies and Reuters [49] claims that plenty of illegal landfills has been closed in the last few years and the sparse information that is available gets outdated quickly.

When discussing environmental problems in China, it's important to remember that China is fighting a “War on Pollution” [32]. Air-bound particles are commonly measured in amounts of particulate matter(PM). The emissions of PM2.5 and PM10 are in focus since they are known to have correlations with respiratory and heart disease. It's thereby crucial to take the air pollutants in to account when handling the waste management system in the mega-cities.

3.2 Food waste management in the context of China and Beijing

The collection of food waste in China does not only pose major infrastructural and technical challenges, but also big social challenges in educating the citizens in environmental awareness [46] to create incentives for source separation as well as food waste reduction. Another social barrier is the general but widespread distrust in the system for treating the separated food waste differently than that which is not separated [28]. This can be clearly observed in locations around Beijing where attempts to source separate organic waste at household level has been introduced. Yet a common sight in these locations is that organic waste contaminated with small but significant amounts of mixed residual waste.

China has a tradition of using food waste as animal feed, something that still is done but is controversial due to the possible spread of deceases if not done correctly [46]. Accurate numbers on how much food waste is being recycled in this way is not available, though most of it can be assumed to come from catering and not from households. According to Zongguo Wen et al. [46] in 2011 China launched a pilot project for treatment of food waste including "collection, transportation, treatment and utilization" of the food waste in 100 cities, including Beijing. More information about the outcome of this project has not been found. They also claim that the food waste treatment is lacking "mature policy support" in China, stressing that laws and implementations are weak. They add that lack of technical standards and knowledge is limiting the development of the food waste-to-energy and resource utilization in China [46]. Though policy support is advancing, in the 13th five year plan it is stated that "we will strengthen the prevention and treatment of pollution caused by hazardous waste" in combination with "We will accelerate the development of urban refuse treatment facilities, improve refuse collection and transportation systems, increase the waste incineration rate, and ensure proper treatment of landfill leachate" [9]. Currently, waste to energy technologies do have financial support through feed in tariffs for the electricity produced as well as a subsidy per treated ton of waste (0.106 $/kWh and 13.04 $/ton) [47].

Both the EU and the US has clearly stated in which order different treatment methods should be prioritized. The EU waste hierarchy can be observed in Figure 2. Contrary to the EU, no stated hierarchy of preferred waste treatment methods in China has been found in research for this report.

Figure 2: European union waste hierarchy [8]

3.3 Landfills as a municipal solid waste treatment method

Landfills, both sanitary and dumpsites, are Beijing's main disposal method for all fractions of municipal solid waste [50]. Every day thousands of tons of food waste ends up in landfills where it produces methane gas which is either partly collected or not collected at all. Sanitary landfills are built to protect the surrounding environment from hazardous substances, materials etc. as well as bacteria from leaking out into the surroundings. This is usually made by using natural barriers and/or creating artificial barriers both towards the ground and air. Dumpsites lack some or all facilities to isolate the waste from the surrounding environment. The amount of dumpsites in Beijing are on a steady decrease [45].

While the chemicals can be contained within the sanitary landfills' protective walls, the gaseous substances needs to be collected. If the gas is not collected, the methane, containing landfill gas will contribute to global warming. The problem with the landfill gas can be solved by flaring or landfill gas utilization after the gas has been collected. The first meaning that the gas is burned and the later meaning that the gas is either used for electricity production or upgraded to CNG-quality [6].

Wang and Geng [45] calculates that 1 kg of municipal solid waste in China can generate 1.16 kg of CO_2 equivalents in sanitary landfill compared to 0.79 kg in dumpsites. Sanitary landfills then represent the highest greenhouse gas emission per kilo which is unfortunate since it is China's, as well as Beijing's, most common municipal solid waste treatment method. Another study found similar results showing that simple sanitary landfills without gas extraction had higher greenhouse gas emissions [641-998 kg CO_2eq/t] compared to that of open dumps [480-734 kg CO_2eq/t] [10].

To estimate Beijing's landfill methane emissions more field research is needed as studies [6] suggest that methane emissions "can vary over seven orders of magnitude depending on waste composition, cover materials, soil moisture, temperature and other variables". While methane production in landfills are high, they also act as carbon storage as more than 50% of the biomaterial in the landfill tend to not decompose and form biogas [6]. In addition to variation of greenhouse gas production at landfills, the landfill gas collection efficiency (meaning the percentage of the produced landfill gas which is collected) at landfill sites equipped with landfill gas collection facilities also varies greatly depending on the construction of the landfill site and the speed of landfill gas production. An average landfill gas collection efficiency is around 75% in the US according to the United states' Environmental Protection Agency [11]. The French environmental protection agency estimates collection efficiencies between 35 and 90% depending on which collection method is being used [33]. This concludes that whichever landfill gas collection method is used, substantial amounts of landfill gas will be emitted from landfills.

Food waste is the fastest decomposing waste category, quickly generating landfill gas. If the waste has a large fraction of organics, landfill gas is quickly generated and the gas collection efficiency drops. The concept of a landfill is to physically isolate the problem of toxic substances in the waste, but it does not solve the problem. Landfill sites contain large amount of toxic substances, usually of unknown type. It is inevitable that these substances gradually leach out, potentially spreading in the natural environment, most commonly dissolved in water but can also appear as toxic gases [27]. The toxic substances that might leach out, the lack of resource utilization and the large amounts of land use necessary are three reasons for the EU to deem landfills the last resort in the waste hierarchy [8]. The United States waste management directives also deem landfill to be the least preferable alternative and considers landfill gas collection to be an energy recovery method [2].

A modern solution for treating the organic fraction of the non-source separated municipal solid waste is to, after mechanical sorting, collect the organic material in a so called biocell, which often is in close proximity to a landfill. The biocell is basically a facility for organic digestion which simplifies the collection of land fill gases, it speeds up the digestive process as well as increases the amount of land fill gas collected. Landfills usually contain plenty of valuable materials which could be used elsewhere and is deemed a poor solution from a resource utilization perspective. They can also cause problems with explosions from landfill gas collections [8] and landfill slides can occur which has taken lives in China even in recent years [26].

According the Swedish natural protection agency (Naturvårdsverket), the fraction of Swedish waste going to landfill has been reduced drastically due to implementations of different policy instruments such as "producer responsibility, national goals for increased recycling, banning landfill as a treatment method for certain waste categories, taxes on landfill in addition to stronger regulations from the EU" [own translation] [27].

3.3.1 Landfills in Beijing

Landfill is still the treatment method used for the majority of the municipal solid waste in Beijing. The quality of the landfills are varying, with about 38% of present landfill capacity equipped with landfill gas collection. Of the collected gas, about 1/3 is used for electricity production, and the rest is flared. This concludes that the majority of the landfills in Beijing would be considered "dumpsites" in Europe according to the European union's criteria for landfills [41].

3.4 Incineration as a municipal solid waste treatment method

Incineration, or simply burning, is the concept of burning the collected waste, with or without source separation first. The method has gained a lot of attention as an opportunity for renewable energy, both in forms of district heating and electricity. From the EU's perspective, "incineration including energy recovery is considered a Recovery operation", second last resort in the unions waste hierarchy whilst "incineration without energy recovery is considered a Disposal operation" - the least preferable option of waste management according to the EU waste hierarchy, see Figure 2 [12].

Incineration is primarily favourable for its ability for volume reduction combined with the energy recovery technology. Major disadvantages include that not all municipal solid waste can be burnt and the leftover ashes must be disposed in a safe way [45]. The leftover refuse is composed of fly ash and bottom ash, both inert materials, the first being hazardous and needs to be dealt with in a way which insures its isolation. If the incineration plant is not well constructed or the after treatment of ash is not handled correctly, hazardous substances might be released into the surroundings. To avoid the leakage of dangerous substances in to the air, the complete burning need to be insured in the incinerator, demanding high temperatures under controlled conditions. Even though the environment is controlled, additional precautions should be taken to ensure the reduction of hazardous substances in the air[8]. A technical solution for increased environmental performance of incineration is putting the bottom ash through a stabilization treatment and using it as cement replacement in concrete. This has been widely researched and sparsely implemented [17].

For incineration to be possible, the calorific value of the waste need to be high enough which until recently hasn't been accomplished in China. Different incineration technologies offer different solutions for this problem while "Grated Furnace" technology demands high calorific values for incinerated waste (5-6 MJ/kg depending on source) and "Fluidized bed" technology handles lower calorific values but the incineration needs to be supported by other fuels eg. coal [47].Wang and Geng [45] calculates that 1 kg of municipal solid waste in China can represent 0.5 kg carbon emissions if incinerated.

3.4.1 Incineration in Beijing

Incineration has been chosen as a preferred municipal solid waste treatment method by the Chinese government amongst others in the 12th and 13th five-year plan due to the quick waste volume reduction it brings, the minor land use, stability and sanitary possibilities with its facilities and energy production of the method [47][48]. Incineration is the only method offering all this and the use of the technique is there by inevitable, claims Zhao Xin-gang et al.[47]. A common way for the government to approach the rising problems of increasing urban waste is the encouragement of building incinerators [51]. The incinerators play a role of great significance in China's municipal solid waste now and in the future, especially grade furnace and fluid bed technologies are promoted. The construction of new incinerators has received a lot of public opposition, mainly based on the danger of substances being released in to the air and affecting the health of people nearby. The heath conflicting substances are depending on the content of the waste that is being burnt. There are several methods for reducing the amount of dangerous chemicals formed during incineration, separating certain plastics is one while controlling the residence time, temperature and turbulence are other [48]. Waste water treatment and air cleansing are two other essential methods for sustainable incineration. Since the separation of hazardous materials in Chinese waste is very sparse, these materials can be assumed to be combusted with the rest of the municipal solid waste justifying the public concern. In spite of protests, incineration is projected to increase in Beijing and throughout China. Whilst being promoted, Beijing's municipal solid waste management is less dependent of incineration than other major cities like Hangzhou where 56% of the municipal solid waste is incinerated [15] whereas Beijing's facilities cover 43% of the total municipal solid waste. Since the municipal solid waste collected in Chinese cities tends to be very wet, with moisture representing 80-90% of the weight of the food waste it needs fuel to burn [46]. It is common practice in China that this is achieved by co-incineration with coal [15].

Data on the treatment of fly ash from Beijing's incinerators have not been found in research for this report. However, Zhang et al. [53] claim that designated facilities for treating fly ash is rare in China. The article also claims that is has often been reported that the fly ash is being placed at dumpsites, strengthening its claim with photographs. Although many incineration venues claim to safely deposit the fly ash, few agree to disclose data.

A life cycle impact assessment of municipal solid waste in Hangzhou shows that the main identified problem in efficiency in municipal solid waste management is the lack of source separation, especially separation of food waste since it lessens the heating value of the municipal solid waste brought to incineration. Lowering the amount of food waste in the incinerated waste could also reduce the need of co-incineration with coal which would lower its emissions of greenhouse gases [15].

The amount information regarding the heat usage from the incineration in Beijing found during research for this report has been small. In Beijing district heating provides heat for about one million inhabitants in public and private buildings. The general energy mix for district heating in China is 48% from coal fired boilers, 42% from combined heat and power plants, 8% from gas fired burners and 2% others. The understanding when writing this report is that there are four major combined heat and power plants in Beijing which are connected to a district heating grid all run by Beijing District Heating group [5].

3.5 Composting as a municipal solid waste treatment method

Composting is a method to treat the organic fraction of the municipal solid waste. It's a microbial process where the food waste is digested into (most importantly) digestate, carbon dioxide, heat and water. The process needs access to oxygen which means that the organic waste needs to be turned over, rotated or somehow stirred to avoid a transition to an anaerobic process.

Composting is a cheaper and simpler method of treating food waste than anaerobic digestion and has been widely promoted, used and functional in Taiwan[7]. The process allows the waste to be recycled in to organic fertilizers. The distribution of the digestate also calls for a well-functioning distribution system. According to Wang and Geng, composting 1 kg of food waste has a carbon emission of 0.3 kg [45].

3.5.1 Composting in Beijing

According to Wang [57], the composting capacity of Beijing is 750 tons per day, representing about 6.4% of the food waste generation in the city. The capacity is not fully used and only 500 tons per day is treated (4.3% of the food waste). Composting is practically only made from the source separated leftovers from the catering industry in the city and only a small fraction comes from private households.

Organic recycling of food waste in Beijing is almost entirely done by composting whilst in Sweden food waste is generally anaerobically digested and only garden waste is composted. According to "Avfall Sverige" only "15 out of a few hundred composting facilities in Sweden is used to treat food waste" [own translation] [38].

3.6 Anaerobic digestion as a municipal solid waste treatment method

Anaerobic digestion is the microbiological process where organic matter is digested to biogas (containing mostly methane) in an oxygen (O_2) free environment. The process involves several different stages each dependent on a different kind of bacteria to take the matter through hydrolysis, acidogenesis and methanogenesis [42]. The bacteria working through these processes are sensitive to changes of environment and content of organic matter. This makes it a challenging process to manage efficiently and complicates exporting efficient methods from western developed countries to China. This since the content of the food waste is of a different composition and external factors such as temperature and humidity are different. Even local conditions fluctuate, such as content of FW, which demands for an active operational staff or automated feedback systems which controls the environment [10].

The most attractive by-product of anaerobic digestion is the biogas which, after cleaning and upgrading, can be used as an replacement for natural gas as fuel for vehicles, heating and cooking as well as for electricity generation. The process of anaerobic digestion of organic matter allows for nutrient recycling of the leftover organic material, the so called digestate. The digestate, which usually is rich in nutrients, allows for selling and using as fertilizer on fields, this could be especially beneficial for countries with high intensity farming, like China, which need to re-nourish its agricultural areas. With higher contents on non-degradable materials in the food waste, the quality of the bio fertilizer lowers, meaning that the food waste going to an anaerobic digestion plant needs to be sorted. This could be done at the site of the production of the garbage (i.e. the catering facility, market or households) or at the anaerobic digestion plant either by labor or mechanically. Sorting out the food waste from the total municipal solid waste at the anaerobic digestion facility would also lower the requirement of a separate infrastructure for dealing with food waste [42]. Sorting at the facility could also solve the problems of distrust and disengagement from the city's residents who do not source separate due to various reasons. The collected biogas from anaerobic digestion facilities is equivalent to that collected as landfill gas, though, in an anaerobic digester, the anaerobic process can be controlled and the process is faster than that of landfills.

3.6.1 Anaerobic digestion in Beijing

Anaerobic digestion is not a new concept in China, in fact it has been around for hundreds of years. Despite the tradition, China's late development in sanitary municipal solid waste management has left the country behind on the construction of full scale anaerobic digestion plants. In 2010 professor Pin Jing He [16] said that "the successful start-up of a high efficient anaerobic digester for municipal solid waste has yet to be reported in China". The expertise for constructing and running a full-scale anaerobic digestion plant has previously not existed in China, which has driven up the prices [47]. In fact, even when operators and equipment has been brought in from overseas, the productivity of the anaerobic digestion plants in China has still been very low [29].

A study conducted at a pilot anaerobic digestion project in Beijing concluded that the biogas production of the facility was extremely low (3% of the expected value) and was only able to handle about 1/3 of the expected volume of food waste [10]. Several factors were identified as limiting during the study, mostly relating to the operators of the plant only observing four parameters, missing important information such as "input volume, fill levels, substrate characterization" etc. The plan was also lacking "visualization and feedback process control" leaving a lot up to the operator of the plant [10]. According to research for this report, anaerobic digestion only exists in small amounts in pilot projects in Beijing, representing a negligible fraction of the total amount of treated waste.

3.6.2 Digestate, organic fertilizer on the Chinese market

The organic fertilizer which is produced as a by-product from anaerobic digestion as well as composting can create revenue as well as environmental savings from productions of the fertilizer it replaces. According to Future market insights, "Strong government policies and rules are expected to contribute to the growth of organic fertilizer market" in the APAC region, including China [18]. As the market for organic agricultural products has grown substantially the last 5 years and is projected to continue to grow in China [24] , it could be argued that the market for organic fertilizer can be assumed to follow this trend.

For the bio fertilizers to be able to be used for agricultural purposes, the safety of it's content must guaranteed, both in terms of hazardous organic substances as well as inorganic substances. During this research, no such system has been found in Beijing. In Sweden, a certification guaranteeing the quality of the bio fertilizer has been introduced as a joint initiative from private and public actors[36].

3.6.3 Biogas on the Chinese market

Natural gas is used extensively throughout the Chinese society for cooking, heating, transportation, production etc. Natural gas has been portrayed as a major problem solver regarding the health compromising air-pollution related to the electricity and heat generation in megacities in general and in Beijing in particular.

During the recent decade, demand for natural gas has increased with an annual growth rate of 17.4% nationwide and even more in Beijing (the same trend can be seen in other Chinese megacities like Shanghai, Guangzhou etc). This has increased the share of gas in the country's energy supply from 2.5% in 2005 to 5.3% in 2013 [52].

As demand for natural gas has grown, there has been a big increase in biogas production as well. From 2003 to 2013 household production increased from 4.5 Gm^3 to 16 Gm^3 per year and large-scale biogas facilities increased from 0.2 Gm^3 to 2 Gm^3. This increase results in biogas representing a fraction of 12,4 % of the natural gas consumed in the country [14].

After recent change of policies, the natural gas price in China is now linked to the price of oil which is market regulated. This increased the price of natural gas in China and supposedly raised incentives for production of natural gas [52]. With this information at hand, it's easy to argue that the market for biogas should be increasing as well, yet in the research done for this report no clear display of production numbers was found. Biogas production and use is widely promoted by the central government and financial support has been distributed although only about 10% of the around 20 billion CNY has been used for producing and running large and medium size biogas plants[54]. The remaining money has almost exclusively gone towards household size bio digesters in rural areas. Yet, in 2020, biogas production is projected to reach 20 Billion m^2 nationwide [23].

Research has been supporting the use of CNG as vehicle fuel rather than for electricity production partly due to its reduction of NOx and SOx in the cities and possibility of approaching full combustion in comparison to diesel and gasoline, especially for vehicles in dense cities. According to IRENA (International Renewable Energy Agency), China already has a "relatively well developed" natural gas vehicle system which easily could be replaced by biogas [20]. This fact is slightly contradicted by Dr. Tao Wang who claims that that the insufficient CNG refueling system is one of the main challenges of the development of CNG and LNG cars in China. Hitherto, the expansion of gas fueled cars has been on a rocky road in China and after gaining attention it lost momentum again in 2012 due to low oil prices [44].

3.7 Table for overview of treatment methods

Table 3: Overview of advantages and disadvantages of different municipal solid waste treatment methods.

Treatment method	**Advantages**	**Disadvantages**
Incineration	· Efficient land use · Waste-to-energy (Electricity) · Short treatment time · Heat for district heating	· Hazardous fly ash needs to be treated · No resource recycling · Risk of toxic air pollutants
Landfill	· Waste-to-energy (landfill gas) · Simple management	· Inefficient land use · Greenhouse gas emissions · Waste water leachate · No resource recycling
Anaerobic digestion	· Waste-to energy (biogas) · Organic fertilizer production · Efficient land use	· Require educated management. · Problematic odours
Composting	· Simple management · Organic fertilizer production	· No energy collection · Inefficient land use · Long treatment time

3.8 Introduction to Life cycle analysis

Life cycle analysis (LCA) is a widely used methodology to calculate the environmental impact of a product or process from "cradle to grave". The environmental impact can include everything from greenhouse gas to land use to resource utilization. The method necessarily includes the following steps.

1. Goal and scope

2. Life cycle inventory (LCI)
3. Life cycle impact assessment (LCIA)
4. Life cycle interpretation

1. Goal and scope - in this section the purpose of the study is defined. The functional unit is determined. The functional unit is the quantity of the product or process that the study will be based on and the results will be dependent on. For ex., it could be one product but it could also be a volume of a substance or one product - depending on the focus of the study. The boundaries of the LCA will also be defined, that is, which parameters will be included in the study and which will not.

2. Life cycle inventory (analysis) - in this section data is collected and analyzed. The allocation of environmental factors is determined. Performing the Life cycling inventory analysis is often the most time consuming part of the LCA.

3. Life cycle impact assessment - in this section the inventory is analyzed, characterized and categorized.

4. Life cycle interpretation - in this section the results of the study are weighted compared to each other and evaluated in order to reach a conclusion[30].

3.8.1 WAMPS

This study makes use of the LCA-based software WAMPS (Waste Management Planning System), developed by IVL Swedish environmental research institute. In the user manual, the program is defined as follows "WAMPS, developed by IVL, is a material flow analysis method, which calculates the energy turnover, emissions and costs regarding different waste management systems in a life cycle perspective". WAMPS simplifies the process of comparing several different waste management options [21] by defining which data is needed for the calculation and there after performs the life cycle impact assessment. WAMPS was originally designed for northern Europeans standards for an initiative involving Sweden, the Baltic countries and Poland and therefore uses underlying statistics from there. This can cause problems since the waste management system and food waste composition is drastically different in Beijing from Sweden (for example), this is further discussed under section 5.7.1. WAMPS software comes with already set system boundaries. The software includes the reduction of environmental burdens "saved emissions" specified as included "alternative production" of gas, heat, electricity and fertilizer. This means for example the natural gas production replaced by the production of biogas. The usage and degree of productivity of these are set after European standards. WAMPS performs a big part of the life cycle inventory. The environmental impact assessment is made automatically with the pre-set background data in the software.

4 Case Study

4.1 Goal and scope

To add a new perspective on the topic of food waste management in Beijing a case study with a life cycle perspective is introduced. The goal of the case study is to investigate the environmental impact and resource utilization impact of food waste management in Beijing, in accordance with the goal of the full report presented in section 2.1. The case study intends to accomplish this by looking at the current system of landfill, incineration and composting and comparing it with a possible future system. The focus is put on increased use of anaerobic digestion but also increased composting and incineration is studied. Anaerobic digestion and composting are chosen as organic treatment methods in this case study. They are chosen because of their ability to treat large amounts of biodegradable waste, large scale solutions for treatment of organic waste already exist and is already utilized in large parts of the world. Using organic waste as animal food was disregarded as a treatment method. Since no clear goals regarding the treatment of organic waste in China could be found, Swedish goals were used in the simulations of the case study.

WAMPS processes the emissions and environmental impacts related to the total amountof waste (tons) produced within the study's boundaries (in this study Beijing) per year. In Beijing this number is 7.9 Mtons according to Beijing statistical Yearbook 2016 [35]. The system boundaries used to gain this life cycle perspective are defined through WAMPS. The known boundaries are described in section 3.8.1 and discussed in section 5.7.1.

4.2 Collection of data and data sources

The data was collected from literature studies, mostly scientific reports, some from Chinese official statistics and statements from Chinese experts or authorities when possible and other from international databases when no local data could be found. Whilst trying to find as recent data as possible, data has been contradicting and vaguely specified which has complicated the process. As recent data as possible has been used in greatest possible extent. When difficult to find accurate data for Beijing, data from other Chinese cities has been used and when Chinese data has been unavailable, international data has been used.

4.3 Scenarios

The scenarios are made to evaluate the environmental benefits of three general trends.

1. An increasing fraction of food waste is being recycled through anaerobic digestion and the usage of of the biogas is varied. These scenarios (S) are named: [S:Anaerobic digestion+(Electricity)], [S:Anaerobic digestion+(Vehicle)], [S:Anaerobic digestion++] and [S:Anaerobic digestion+ & Incineration+]..

2. An increased fraction of food waste is being recycled through composting, [S:Compost+].

3. An increasing fraction of municipal solid waste is being diverted from landfills to incineration facilities, [S:Incineration+] and [S:Anaerobic digestion+ & Incineration+].

The trends are chosen with the intent to compare composting and anaerobic digestion as large scale municipal solid waste treatment methods to each other and in comparison to incineration of the mixed residual waste. Incineration is chosen for comparing since it is widely promoted in China, see section 3.4.1. The scenarios are constructed as one base scenario describing the present situation of MSW treatment in Beijing, four half way scenarios and two goal scenarios. The goal scenario represents the weight of 50% of the organic waste being organically recycled, a number based of the goal scenario for Swedish organic waste treatment [37].

Each scenario is named after the increased treatment method(s) followed by one or two plus(+) signs. One plus sign(+) represents a 977000 tons/year increase of the waste treated with this method. Two plus signs(++) represent a 1.95 Mtons/year, which is the double amount as that of one plus. For extra clarification, these weights are presented in table 4 as well. The (++) weight represent 50% of the food waste generated per year in Beijing. The (+) weight is a half way scenario in between current situation of 4.6% organic recycling to 50 % organic recycling of the generated food waste.

Table 4: Each future scenario has a set amount (weight) of waste redirected to a specified treatment method. These weights are either represented by one plus signs(+) or by two(++) depending on the amount of waste which is treated with a different method than that of base scenario, [S:Base],.

Symbol	**Mtons of redirected waste**
+	0.977
++	1.95

In each scenario a set amount of waste is diverted from landfills to the three alternative treatment methods, incineration, anaerobic digestion and/or composting. Apart from the modelled increase in treatment capacity specified in each modelled scenario, the already installed capacity of treatment facilities in Beijing for treating the remaining mixed residual waste is prioritized in the order of:

1. Full incineration capacity (3.40 Mtons/year [56])

2. Full landfill capacity (with landfill gas collection, 1.64 Mtons/year [58])

3. Remaining amount of mixed residual waste is sent to dumpsites

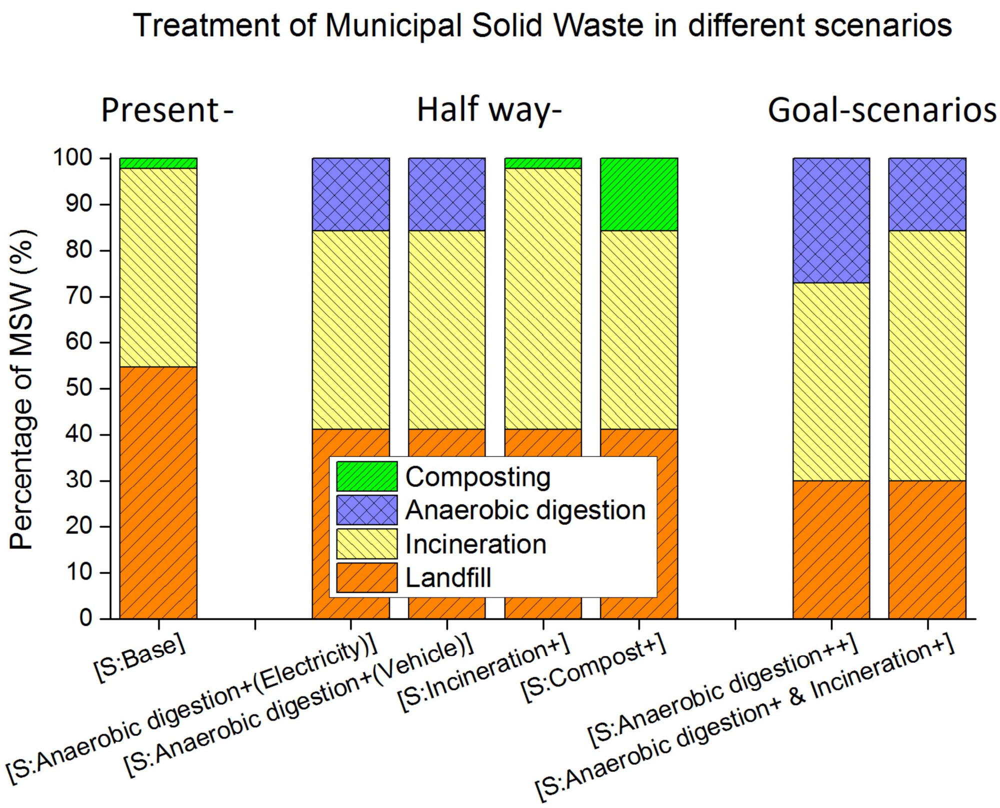


Figure 3: Display of the seven scenarios and fractions of each treatment method for each scenario. Dumpsites are included in the landfill segment. The scenario's are placed together with other scenario's which have the same amount of redirected waste compared to the base scenario S:Base. This makes the halfway scenarios comparable to each other and the goal scenarios comparable to each other. The general trends of waste being redirected from dumpsites can be seen comparing the three groups.

[**S:Base**], is the base scenario based on present data of the waste management in Beijing.

[**S:Anaerobic digestion+ (Electricity)**] and [**S:Anaerobic digestion+ (Vehicle)**], are modelled scenarios with an increased amount of anaerobic digestion. The amount of food waste which is source sorted is increased by 0.977 tons/year. The total amount of anaerobically digested waste is increased to 27.2% of the organic fraction of the municipal solid waste. In [S:Anaerobic digestion+ (Electricity)] the gas is used for electricity production, whilst in [S:Anaerobic digestion+ (Vehicle)] the gas is used as vehicle fuel. In all other respects the scenarios are equal.

In the [**S:Incineration+**] scenario 0.977 tons/year is increased to the incineration capacity. This scenario has no increased source sorting.

[S:Compost+] uses the exact same parameters as [S:Anaerobic digestion+ (Electricity)] and [S:Anaerobic digestion+ (Vehicle)], but the 0.977 tons/year increase in source sorted food waste food waste is being composted instead of anaerobically digested. This results in 27.2 % of the organic fraction of the municipal solid waste being composted.

In Scenario **[S:Anaerobic digestion++]** 50% of the food waste is source sorted and treated with anaerobic digestion, this an increase with 1.95 Mtons from the base scenario, [S:Base].

[S:Anaerobic digestion+ & **Incineration+]** is combining anaerobic digestion and incineration. Each treatment methods is increased with 0.977 Mtons/year. This results in the same amount (weight) of waste being alternatively treated as in [S:Anaerobic digestion++].

Example: In the modelled scenario [S:Compost+], the increase in food waste source sorting and organic treatment is 0.977 Mtons/year. Composting is being increased with this capacity and the fraction of food waste in the mixed residual waste is thereby reduced as well as the total amount of mixed residual waste that needs to be treated with incineration, landfill and dumpsite. First, present incineration capacity is maximized, meaning 3.40 Mtons of mixed residual waste is being incinerated. Secondly, present landfill (with landfill gas collection) capacity is being maximized, meaning 1.64 Mtons of mixed residual waste is sent to landfill. Remaining 1.88 Mtons of mixed residual waste is sent to dumpsites.

When the results of the scenarios are evaluated and compared, it is most relevant to compare those where equal amounts of waste is being redirected from the base scenario [S:Base] to other treatment methods. Meaning it will thereby be most relevant to compare scenarios with one plus(+) with each other (the half way scenarios) and scenarios with two plus (++) or two times (+) with each other(the goal scenarios). For this reason, scenario [S:Anaerobic digestion+ (Electricity], [S:Anaerobic digestion+ (Vehicle)], [S:Incineration+] and [S:Compost+] are placed together in Figure 3 while [S:Anaerobic digestion+ & Incineration+] is placed together with [S:Anaerobic digestion++] in the same figure.

Note that none of the scenarios alter the incoming amount of municipal solid waste, which is constant at 7.9 Mtons/year [35] in the base scenario, [S:Base], as well as in the six modelled scenarios. The composition of the waste is not altered in the different scenario and is shown in Table 2 and in Table 5 Appendix 1. For a more systematic overview of the parameters inserted in WAMPS for each of the scenarios, study Table 5 in Appendix 1.

4.4 Assumptions and clarifications

- There is no mechanical or central sorting of food waste in the base scenario, [S:Base]. The increase of organic recycling is in all relevant scenarios modelled as result of increased source sorting. In scenarios where the food waste recycling increases, there will still be no mechanical or central sorting of food waste.

- No data on present usage of bio fertilizer from compost could be found in this report. In the the base scenario, [S:Base] and the scenario with increased composting, [S:Compost+] it is set to 50%.

- The replaced energy mix is assumed to be similar to Polish average since the options in WAMPS are limited. This assumption is based on which mix is the most similar to the Chinese mix, out of Sweden, Lithuania, Estonia, Latvia and Poland according to IEA, International Energy Agency [1].

- Except from the treatment method preferred for each scenario, the present facilities will be used to full capacity in the following order: Incineration, landfill with landfill gas collection, landfill without landfill gas collection. This will leave the incineration capacity mostly static (in scenarios that do not alter the incineration capacity), the landfill sites (with landfill gas collection) will also receive a mostly static amount of municipal solid waste. Thus, it is the amount of municipal solid waste processed through dumpsites that varies the most between scenarios.

- WAMPS demands a specified value for how much waste is going to landfills which meets up to European standards and how much that goes to dumpsites, defined as landfills which doesn't live up to EU standards. In this study, sites in Beijing with landfill gas collection are assumed to reach EU standards.

- Data regarding distance of transportation of waste, collection occasions and capacity of municipal solid waste truck has assumed to be equal per kilo food waste as that of mixed municipal solid waste.

5 Results and discussion

5.1 Discussion of literature studies and resource utilization

Judging from the literature studies, continuing to use landfills and dumpsites as the main treatment methods is not environmentally acceptable nor the planned development path for Beijing's municipal solid waste management. Thereby the main discussion regarding future treatment methods for Beijing's municipal solid waste focusing foremost on food waste remains to be incineration, composting and/or anaerobic digestion. Judging from literature studies, composting has no clear environmental advantages over anaerobic digestion. Therefore, the focus of of this subsection.

According to the data found on the composition of waste in Beijing, see Table 2, there is no hazardous waste in Beijing. This data can't be correct. It is likely, that this undetected hazardous waste is treated with the other mixed residual waste in landfills, dumpsites and incinerators. It is also possible that that unknown amounts of hazardous waste is mixed in to the organic waste, contaminating the bio fertilizers and questioning its quality. Incineration may be dangerous for both health and environment if the inbound waste is hazardous, the facilities aren't safely constructed and managed to collect hazardous substances or if the fly ash isn't treated cautiously. If so it could have negative effect on both environment and nearby residents. In addition to this the lack of data on the procedure of isolating the hazardous fly ash is concerning, regardless of the amount of incoming hazardous waste. Depositing unknown amounts of hazardous waste in landfills and dumpsites is also questioning the safety of the surrounding environment.

Incineration is an easy method to implement in large scale in Beijing as there is no need for source separation. Increased amounts of anaerobic digestion and composting would demand separated waste collection as well as source sorting by the city's inhabitants. Not only would it mean a challenge to educate a very large population but also a need to build up trust in the authorities that the sorted waste will be treated correctly. Another fact that simplifies a larger implementation of incineration is that knowledge on how to build and work incineration plants already exists. While anaerobic digestion venues have had difficulties generating biogas from the organic waste.

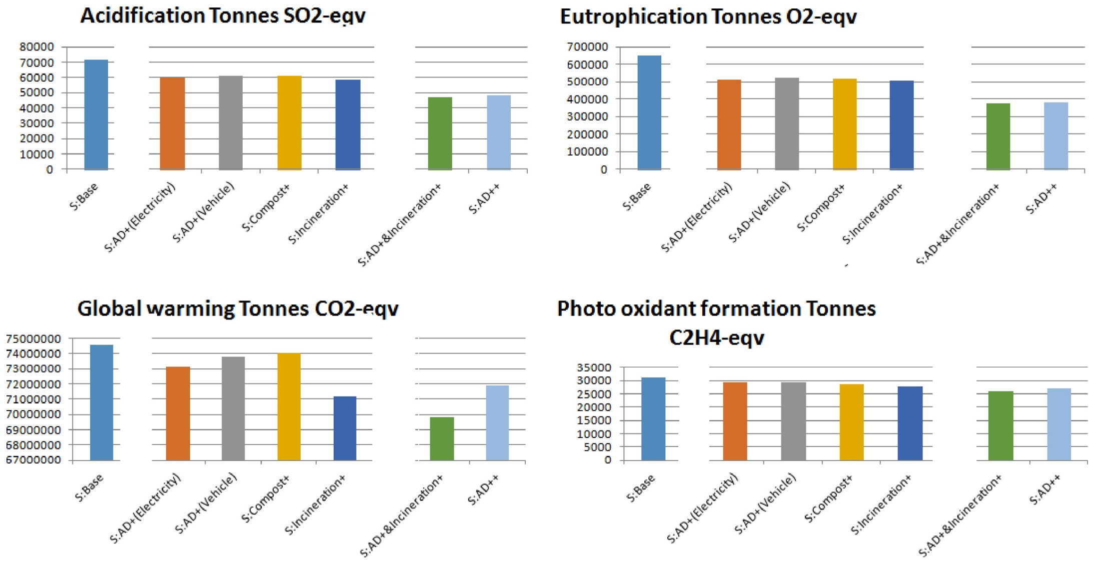
Since anaerobic digestion allows for food nutrients to be recycled and energy recycling while incineration allows for high energy recycling they appear hard to compare. Yet, food waste has been seen to lower the heating value affecting the energy output from incineration, insinuating that treating the food waste separately would be environmentally preferable. Since the food waste in Beijing is very wet, it is not ideal for burning. This is enforced by the low heating value of Beijing's waste which is just barely high enough to enable incineration. If the waste needs to be co-incinerated with coal, its negative environmental impact would increase.

Judging from literature studies, aerobic digestion would be a environmentally beneficial method allowing for both volume reduction, resource utilization, reduction of fossil fuels as an electricity production or vehicle fuel replacement. The possibility of the bio fertilizer being used calls for strict regulations and certifications which will have to gain trust by farmers. With the combination of resource utilization by re-introducing the nutrients of the food waste via the bio fertilizer to the market as well as allowing for energy recovery. From literature studies carried out for this report, anaerobic digestion is deemed to be more efficient method from an environmental impact and resource utilization perspective than incineration. This as valuable resources are lost in the incineration process.

5.2 Balancing of environmental impact categories

When balancing the gained LCA perspectives against each other in the environmental impact assessment, the local conditions must be taken in to account. In an urbanized environment, within a mega-city like Beijing, the environmental burdens that are hazardous for health in the nearby area are for example a bigger concern than those of acidification, whilst in sparsely populated areas, it might be the opposite. An example of this is the "War on pollution" mentioned in Section 3.1. Keep in mind the assumptions mentioned in section 4.4, when observing the presented results.

When electricity is generated by combustion of coal, a lot of particles are released in to the air. This results in electricity that is produced via waste-to-energy technologies and reduces this “dirty” electricity is deemed to result in negative emissions. If coal was to be replaced by other means of greener electricity production, that would also mean that the environmental benefits of the waste-to-energy alternatives would be reduced. An overview of the results from the case study are displayed in Figure 4. Since WAMPS is developed for northern European countries, some uncertainties are added to the results, for further discussion regarding this see Section 5.7.1.



Category	Unit	S:Base	S:AD+(Electricity)	S:AD+(Vehicle)	S:Compost+	S:Incineration+	S:AD+& Incineration+	S:AD++
Acidification	Tonnes SO2-eqv	71527	59738	61391	61027	58647	47038	48417
Eutrophication	Tonnes O2-eqv	648745	512544	521247	516387	507243	372602	379362
Global warming	Tonnes CO2-eqv	74603219	73176324	73789153	74091499	71208738	69825414	71937788
Photo oxidant formation	Tonnes C2H4-eqv	31217	29262	29225	28625	27791	25812	27168

Figure 4: The WAMPS results from four categories Acidification, Autrophication, Global warming and Photo oxidant formation.

5.3 Impact of increased anaerobic digestion

When studying the effects of landfill and dumpsites being replaced by anaerobic digestion reflected by scenario [S:Base], [S:AD+ (Electricity)] and [S:AD++] in Figure 4, the base scenario is the least environmentally beneficial one. As food waste is being diverted from landfills, especially dumpsites, to anaerobic digestion the environmental impact categories all decrease. This is both based on the avoidance of methane being released in to the air in landfills (especially those without landfill gas collection) and to the electricity that is being produced by anaerobic digestion, partly replacing the current energy mix which contains a large fraction of coal. To conclude that the same trend would exist if the assumption about the landfill/dumpsite ratio would have changed since the data was retrieved, an alternative run was made where 100% of Beijing's landfill sites were assumed to reach European standards. This assertion experiment was run due to the quick upgrading of dumpsites to landfill facilities in Beijing and the slightly old data the landfill capacity was based on. The results show the same general pattern whether the waste is sent to dumpsites or to landfill sites. This is expected and follow the results of other studies as well as the EU waste hierarchy.

5.4 Comparison between increased anaerobic digestion and increased incineration

When investigating the [S:Incineration+] scenario, the environmental benefits of using incineration on the same mass of municipal solid waste as that of food waste in [S:AD+ (Electricity)] all impact categories clearly lean towards incineration as being the most environmentally beneficial according to WAMPS. Meaning that a progression of treating general waste through incineration would be more beneficial than source sorting and treating the food waste with anaerobic digestion, regardless of weather the biogas is used as vehicle fuel or as electricity. This scenario is enhanced by seeing that [S:AD+ & Incineration+], combining the source sorting and organic treatment of [S:AD+ (Electricity)] with the increasing incineration capacity of [S:Incineration+] also gives better environmental performance in all environmental impact categories compared to [S:AD++] (where equal amount of waste is diverted from landfill).

5.5 Comparison of biogas utilization

As can be seen in Figure 4 when comparing [S:AD+ (Electricity)] and [S:AD+ (Vehicle)] the environmental impact categories only vary marginally depending on weather the biogas is used as vehicle fuel or for electricity production. The emission rates of air bound particles are also very similar, see table **??**. Though the results are similar, they are all, except from "Global warming", slightly leaning towards vehicle fuel being the preferable utilization. In table **??** the PM emissions for each scenario are similar, however it is not only the amount of PM generated that is important, but also the location of the polluting source. If the biogas was used for electricity production, it would reduce the amount of particular matter at the location of the plant. However, vehicle related PM emission in central Beijing is an urgent problem which could be addressed by using CNG driven vehicles as well as electric vehicles (where the later would involve two energy conversions rather than one). Thus it is reasonable to assume that using biogas for vehicles would have a positive impact on PM values in the city.

5.6 Comparison of composting and anaerobic digestion

The results of the composting scenarios, [S:Compost+] are dependent on the method of composting, but since the methods to be used in Beijing is unknown, these scenarios are quite speculative. Due to this, the composting method is varied to investigate the difference in results. Open window composting is calculated for reference but gives less environmentally friendly results and is also unlikely to be newly built in an urbanised environment. The WAMPS results provided regarding composting are surprising; dynamic reactor composting has a lower environmental impact than in scenario [S:AD+(Electricity)] in all categories except "Climate change" where the impacts are slightly higher, see Figure 4. Whilst closed static composting have results very similar to that of [S:AD+(Electricity)] yet lower impact in the "Photo oxidant formation" category and higher impact for "Climate Change". The general results of the compost related scenarios is thereby that is equally or more environmentally beneficial than anaerobic digestion of equal amounts, regardless what the biogas is used for. This is surprising since the they both produce fertilizer but anaerobic digestion allows for more biogas to be produced and collected as well.

5.7 General discussion of results

The results from the the life cycle perspective analysis done for this study are in many ways surprising, partly because they do not go in line with the waste management guidelines of the EU's waste hierarchy, Figure 2. The reason why the WAMPS results don't agree with the waste hierarchy is likely because the waste hierarchy considers resource utilization whilst the LCA perspective study only considers emissions related to waste management system. Since the outcome of the LCA is leaning towards environmental benefits of "Other recovery" rather than "Recycling" which is higher up on the waste hierarchy). This strengthens the theory that China's waste needs to be dealt with in a different manner then that of developed western countries - or that the assumptions made for this research and parameters used in WAMPS are too inaccurate to give useful results. Since the anaerobic digestion in China only have succeeded in recovering minimal amounts of biogas compared to northern European standards, the anaerobic digestion system would likely be less beneficial than the results shown. Though anaerobic digestion in China is expected to reach higher biogas recovery efficiencies, approaching those of Northern Europe is yet to be observed.

When studying the results in Figure 4, it's clear that remaining in the base scenario the least environmentally friendly alternative. This is largely based on the energy recovery potential that exists in the waste which in the base scenario largely is put in landfills and dumpsites. The second main reason for the base scenario to be so non beneficial is the present large reliance on coal power in China, resulting in both green house gases and other pollutants. The replacement of this dirty energy is a large part of the positive effects seen when comparing the present, half way and goal scenarios in Figure 4. Assuming that China is transitioning from coal based electricity production towards more renewable and less polluting sources, the electricity generation from anaerobic digestion, incineration and landfill gas would be less environmentally beneficial since the "saved emissions" would be reduced. In addition to that, the approximation of China having a Polish electricity mix makes the replaced energy appear more polluting than it is. The efficiency of incineration also need to be questioned because of the high moisture level and low calorific value of the waste, though it's not confirmed in Beijing, it is common practice in China with co-incineration with coal; which lowers the environmental benefits of the incineration. Another worrying fact regarding incineration in Beijing is that negligible source sorting of hazardous waste and close to no material recovery facilities leaving hazardous and bulk waste with health questioning substances to be incinerated. This is not something that is accounted for in the case study since no data of hazardous waste could be found and was therefore not inserted to WAMPS.

It is essential that China reduces its energy reliance on coal in order to reduce its environmental footprint. All MSW treatment methods contributing to the reduction of coal used in the energy mix is beneficial compared to the present scenario from a pollution point of view. However, incinerating large amounts of waste is wasteful of natural resources and should therefore be limited.

5.7.1 Functionality of WAMPS software in China

WAMPS is a software specifically developed for a few northern European countries and thereby specialized on the occurring problems and municipal solid waste management systems there. The software has a few obvious limitations when used overseas including, but not limited to, the limited number of options of region's electricity production, no option for co-incineration with coal, no possibility to edit food waste content and limited choices of vehicles for municipal solid waste transportation. Northern European conditions differ from Beijing's densely populated urban area and a clear example of this is the small sized electric three wheeled mopeds which are commonly used for municipal solid waste collection in central Beijing but never seen in northern Europe. Several of these limitations could easily be altered if WAMPS is to be used more frequently in the Chinese context.

For China and many other emerging economies, complications regarding efficiency of biogas production has been a problem. As mentioned in section 3.6, the biogas productivity of some anaerobic digestion facilities has been extremely low. There is no possibility for users to adjust the settings to compensate for this in WAMPS.

Chinese waste composition is wet compared to northern European which lowers the heating value of the waste, which is problematic for incineration. This either demands for drying facilities to be constructed or for fuel (often coal) to be used in the incineration process. There is no possibility in WAMPS to compensate for the emissions related to this which has shown to have quite a big impact on the environmental footprint of incineration in China.

Since the results of the case study doesn't align with the expected results from the literature study, some underlying parameters must be too unaligned with Chinese conditions to give useful results.

6 Conclusion

Beijing's municipal solid waste management system has a great potential for improving its environmental impact and according to this study, both literature- and case-study, most established alternatives to the present system which rely heavily on landfill and dumpsites, would mean an improvement. According to literature studies, increased amount of food waste treated with anaerobic digestion would be environmentally beneficial, especially when sorted out from residual wasted and combined with incineration. According to literature studies the efficiency of incineration would be decreased by waste with high moisture content such as food waste. There are no clear environmentally beneficial parameters promoting composting of food waste over anaerobic digestion.

Judging from the case study preformed for this report, the most environmentally beneficial treatment method for Beijing's municipal solid waste would be to extend the amount of incineration. Regarding potential separated treatment of food waste, the positive environmental impact of this was observed to be less than that of incineration which outperformed anaerobic digestion as well as composting in all environmental impact categories in the case study. This conclusion is largely a result of the replacement of the polluting coal based electricity production with the comparably cleaner electricity from incineration. The case study did not consider the limitations and advantages with preservation of natural resources which is one reason for the conclusion to not be consistent with the waste hierarchy. Major questions remain regarding, among others, landfill gas collection efficiency, potential biogas production ability at anaerobic digestion facilities and the distribution and trust in sanitation regarding organic fertilizers from waste are a few of them.

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7 Appendix

	S0	S1	S2	S3	S4	noAD	S5
Source sep. % of Food waste	4,30%	27,15%	50,00%	27,15%	27,15%	4,30%	27,15%
Landfill %	56,00%	49,60%	41,10%	49,60%	35,20%	43,40%	49,60%
% Landfill w. LFG collection	38,00%	49,10%	69,30%	49,10%	69,30%	43,40%	49,10%
Gas use: Electricity (Landfill)	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%
Gas use: District heating (Landfill)	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Gas use: Excess heat (Landfill)	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%
Heat use: Electricity (Incineration)	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	
Heat use: District heating (Incineration)							
Heat use: Excess heat (Incineration)	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	

		Composition	
Total amount of waste	7900000 tons\year	Food waste	53,96%
Total amount of foodwaste	4262840 tons\year	Plastic	18,67%
		Paper	17,64%
Total installed landfillgas capacity	1642500 tons\year	Wood	3,08%
Total installed incineration capacity	3397000 tons\year	Soil and dust	2,15%
Total number of inhabitants beijing	21700000 persons	Glass	2,07%
Total number of households in Beijing	177241 households	Textil	1,55%
		Brick	0,57%

Figure 5: A few chosen parameters inserted in WAMPS, for more detailed information, contact author.

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Figure 6: References in Chinese.