Current status of food waste generation and management in China

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Abstract:

The current status of FW generation, including its characteristics, management, and current challenges in China, were analyzed, and further suggestions were made with regards to improvement. About 19.50% of the FW generated could be treated under the current designs for treatment capacity in China. FW characteristics show great variability in different economic regions in China, where both treatment efficiency and FW management are poor. Combined pretreatment and three-phase separation is the most used pretreatment method, and of the current FW pilot projects, anaerobic digestion is the most prevalent, accounting for 76.1% of all projects. Significant regional characteristics have been identified regarding FW generation and the treatment capacity for FW processing. Possible factors influencing FW management in China were also discussed. Finally, detailed suggestions are given for further development of FW treatment capacity, particularly regarding potential technical routes and management measures.

Keywords:

Food waste; Treatment; Management; Production; Further development

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1. Introduction

Food waste (FW) is a key issue, which has direct environmental, economic and social impacts, in attempts to achieve global food security and good environmental governance (Dahiya et al., 2017; Stenmarck et al., 2016). In China, the Circular Economy has been proposed to reduce, reuse and recycle FW (Dodick and Kauffman, 2017). As an agricultural country with a population of about 1.4 billion people, food worth over 200 billion Yuan is thrown away annually, while economic development and population growth result in increasing generation of FW (Li et al., 2016; Zhang et al., 2014). Currently, issues related to FW include odours, greenhouse gas (GHG) emissions (Cerda et al., 2017) which are considered as major threats to the sustainable development of food production system both in developed and developing countries (Thi et al., 2015). Therefore, timely and effective management is required in order to conserve the energy and minimize the environmental impacts associated with FW (Salihoglu et al., 2018).

Recently, the rapid development of the Chinese economy and the growing environmental consciousness of the government and citizens have also led to the rapid development of FW treatment capacity in China. As an important means of environmental protection, the construction of FW treatment plants has attracted considerable attention. China has made major contributions to its FW management capacity. Between 2011 and 2015, 100 pilot projects were established by four ministries[†] to enhance FW resource recovery. FW treatment typically consists of

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anaerobic digestion (AD), composting, and animal feeding, while the treatment capacity of these methods ranges from 20 to 3990 tons per day. There is still a large gap between the amount of FW generated and designed capacity (30,000 tons per day) according to the 12th Five-year Plan for Economic and Social Development of the Peoples Republic of China (2011 to 2015). Moreover, China has issued specified policies and regulations on FW management (Bi et al., 2016). However, the FW generated in different regions and seasons often varies in terms of total solid (TS), volatile solid (VS), crude protein (CP), Carbohydrate (CA), and ether extract (EE) compositions (Galanakis, 2015). Therefore, the high production and significant variation in the composition of FW creates a large challenge for countries with a vast area, large population and the major differences between regions, urban and rural areas, and ethnic groups.

The rapid construction of FW treatment facilities during the 12th five-year plan has been completed and the 13th five-year plan (2016 to 2020) has recently been released. This is a good opportunity to summarize and analyze the current state of FW management in China. FW treatment in China consists of a variety of processing technologies, treatment scales, and recycling methods, and this state-of-the-art review will assess to identify a focus for researchers and engineers to support future policies and business innovations. However, little systematic research on the current state of FW management in China is available. Information from previous relevant studies needs to be updated, and some results, such as the amount of FW generated nationally, are inconsistent (40 to 90 million tons per year) (De Clercq et al., 2016; Yang et al., 2012; Zhang et al., 2014).

This paper aims to provide a comprehensive review of the current state of FW treatment facilities in mainland China and clearly identify future research directions. The review covers FW policies and strategies, the volume of FW generated and its characteristics, and the treatment and disposal technologies used in facilities, mainly focusing on the 100 FW pilot projects from the 12th five-year plan. Data has been collected from a range of sources including the China Statistical Yearbook, scientific literature, and government reports. Following the review of data, the second part of this paper discussed the problems encountered during pilot projects, relating to influencing factors and their priorities. Finally, the key bottlenecks for effective FW treatment and further suggestions about technical routes to improved management of FW are analyzed in accordance with current changes and future perspectives.

2. FW policies and strategies in China

2.1. Administrative authority

There are about 12 administrative departments in China responsible for the reduction, reuse, and recycling of FW. The following four ministries are at the same administrative level and their functions interact and overlap.

a. The Ministry of Housing and Urban-Rural Development of the People’s Republic of China (MOHURD) is the competent department for solid waste treatment and disposal in China.

b. The National Development and Reform Commission of the People’s Republic of China (NDRC) is responsible for the investment and funding and the formulating and implementation of strategies in annual, medium and long-term development plans.

c. The Ministry of Environmental Protection (MEP) is responsible for the overall coordination, supervision, and administration of the prevention and control of environmental pollution.

d. The Ministry of Agriculture (MOA) is responsible for the supervision and management of the reuse of FW as an agricultural fertilizer and animal feed.

Under this circumstance, government ministries and agencies in China currently work rather independently, and their functions to a certain extent are interactional and overlapping. There are some practical limitations arising from each agent managing FW from their own interest and responsibility, causing inefficiencies in the implementation of FW policies and regulations (Thi et al., 2015). Therefore, all the stakeholders including government departments from the highest level to local level committees and related enterprises need to work together to promulgate policies and regulations relevant to addressing FW issues from a legislative point of view.

2.2. Policies and regulations

2.2.1. National regulations and policies

Currently, FW management in China is covered by seven laws, three national standards, and eight ministry standards. These laws provide a basis for FW management from a macro-level perspective and there are only one or two articles prescribing the general requirements for aspects such as secondary pollution prevention, food safety precautions, safeguarding ecological security and promoting sustainable development.

The standards can be grouped into three categories (national standards, ministry standards, technical regulation and guidelines), which cover various aspects such as the treatment, disposal, classification, and illegal utilization of FW. National standards, prefixed ‘GB’, are mandatory and are the basis for product testing, where products must undergo China Compulsory Certificate certification, while recommended standards are prefixed ‘GB/T’. Meanwhile, ministry standards and technical regulations and guidelines relevant to FW are referenced because they are adapted to dealing with municipal solid waste in general instead of being specifically used to addressing FW issues. The review of the experiences in terms of policy literature on FW management from developed countries revealed that it would be necessary to establish the specified objectives for reducing FW and implement comprehensive legislative regulations when solving the FW issues (Thi et al., 2015).

Besides, of these macrolevel standards, most notable is the technical code on FW treatment, issued by MOHURD to ensure that the ‘3Rs’ (reduce, reuse, and recycle) are applied to FW and the standardization of FW treatment projects. It should be noted that the products recovered from FW are required to meet specified product standards such as for fertilizer, animal feed, or feed additives, according to this code.

Additionally, the technical standards on recycling and deep processing of waste oil from restaurants and the technical regulations for the operation and maintenance of FW treatment plants have passed the consultation stage and will soon be issued, which may specify requirements for the operation and management and the maintenance and safe operation of facilities, as well as environmental monitoring.

2.2.2. Administrative measures at local government level

Local governments also formulate administrative measures in accordance with relevant laws and regulations as well as on the basis of the actual situations. Compared with national regulations and policies, these measures are much more focused on the collection, transportation, disposal and monitoring of FW within the territory of local governments.

Since 2010, a number of policies, regulations, and laws have been implemented based on the establishment 100 pilot projects in 100 cities of China. All provinces and 79% of the cities involved in the pilot projects have issued administrative measures for FW management, while 5% at the consultation stage which have not approved the regulations or finished the consultation and as such, have not yet been implemented.

Pilot cities ratified at the later times are less likely to have administrative measures, or may still be in the preparation stage. Among the 75 cities that published regulations associated with FW collection, transportation, and disposal, 14 cities had already published these in 2010 and another 9 published regulations in 2011, the pilot project start-up year. Forty-eight cities published regulations between 2011 and 2015, when 100 pilot cities were ratified in five batches. Between 2016 and 2018, another 13 cities issued regulations. Moreover, cities that were not involved in the pilot cities issued administration measures (e.g. Zhoushan in Zhejiang province, Zhongwei in Ningxia province, Haikou in Hainan province and Guangyuan in Sichuan province).

2.2.3. Current problems with regulations

Governments need to establish the specific objectives for reducing FW and also implement comprehensive legislative requirements in order to effectively solve FW problems (Thi et al., 2015). So far, China has made significant progress in specifying FW policies and regulations to promote FW management, such as source-separation, collection, and local treatment. However, to enhance these activities, the reasonable integration of these laws and overall regulation of FW by a superintendent should be established. Practical guidance for following FW management standards and technical regulations should also be strengthened in the following areas: a) Specific standards on FW management (e.g. treatment, disposal, products), instead of references for other FW products. b) Regular revision of standards in order to maintain relevance. Some standards, for example the Control Standards for Urban Wastes for Agricultural Use, have not been updated since 1987. c) Vagueness of many standards, meaning their applicability, operability, and practicality can not be guaranteed. In some developed countries, such as the USA, laws and regulations can be found for specific states (AAPFCO). Therefore, policies, regulations and official plans which are more targeted, applicable and maneuverable should be issued.

2.3. Treatment capacity designed in Chinese five – year plan

2.3.1. Requirements in the Chinese 12th five-year plan

According to the 12th five-year plan, there should have been 242 FW treatment facilities in 31 provinces in Mainland China with a total treatment capacity of 30,220 tons per day for a special fund of 10.90 billion Yuan approved by the government.

FW treatment facilities and capacities are constructed more frequently in more economically developed regions. Eastern China, with a high GDP and population density, has the highest capacity (15,220 tons per day) and number of facilities (98). The average capacity of these facilities, was highest in Eastern China (155 t/d), followed by Northeast China (144 t/d). Central China, covering the largest areas of land and a low GDP, had the lowest treatment capacity (86 t/d).

2.3.2. Targets in Chinese 13th five-year plan

According to the 13th five-year plan (2016 to 2020), the Chinese government will the Chinese government will provide a special fund amount to 18.35 billion Yuan, accounting for 7.29% of the total construction investment for municipal solid waste (MSW), in establishing new processing capacity of 34,400 tons per day. After the implementation of this plan, the total capacity could amount to 64,620 tons per day, which is double the requirement in the 12th five-year plan. An increase of 64–128% of total designed treatment capacities of four regions could be achieved by 2020 compared with the value at the end of 2015. Eastern China has the highest planned capacity (30,920 tons per day); other areas ranged from 5,140 to 15,080 tons per day.

According to the 13th five-year plan, apart from an increase in treatment capacity, other requirements have also been included. First, each province is required to establish basic FW recycling and recovery systems. Secondly, regulations on FW management and product standards for FW reuse need to be researched and developed. Therefore, it is expected that a number of policies and laws promoting the comprehensive reuse of FW will be implemented by the end of 2020. Thirdly, when applied to new feedstocks, such as FW with a high moisture or lipid content, existing engineering designs, which are limited to known feedstocks or previously tested process conditions, usually perform poorly or even fail (Chang and Hsu, 2008). Therefore, it was required in the 13th five-year plan that FW generation and FW compositions (physical and chemical characteristics) need to be considered when constructing new treatment facilities. Fourthly, the main treatment techniques is preferred in the plan are AD, animal feeding (feed additives) and energy recovery, while the selection of the treatment process must conform to the specification in the Technical Code for Food Waste Treatment. Fifthly, conducting MSW sorting activities is required to improve the quantity and quality of collected FW as some FW, especially for from households, is mixed with MSW in China due to an inadequate source classification system. Finally, regulations and standards are required to be improved and consolidated to create an enabling environment for the development of FW recycling.

3. FW production characteristics in China

3.1. FW production

Data on the amount of FW being generated in China is not available from official statistics or literature. This generation is estimated based on the Technical Code for Food Waste Treatment, and information regarding such as FW generation, Gross Domestic Product (GDP) per capita[‡], and annual Disposable Personal Income (DPI[§]) of 32 provinces in mainland China was collected.

3.1.1. Geographic distribution

[‡] GDP per capita could be used as an indicator of living standard, with higher value equating to a higher standard of living;

[§] DPI is the money that households have available for both spending and saving after the income taxes is accounted (DPI = Personal income – personal income taxes payments).

An estimated 56.57 million tons of FW was generated in 2015 in mainland China, ranging from 40 to 90 million tons reported in the literature (De Clercq et al., 2016; Yang et al., 2012; Zhang et al., 2014) (**Fig. 1A**).

Eastern China accounted for the largest portion of FW generation (43.18%), followed by Western China and Central China. Approximately 8% of the overall FW was generated in the Northeast China. Provinces in Eastern China also exhibited the greatest variability in FW generation (0.43 to 5.15 million tons). The smallest variations were found in Northeast China (1.16 to 1.84 million tons), and similar variations were also noted for both Central and West China. **Fig. 1.**

3.1.2. Possible factors affecting FW production

Parameters including population, GDP, GDP per capita, output of major agricultural products (OMAP), the gross output value of farming, forestry, animal husbandry and fishery (GOVFFAHF) and annual DPI varied widely among the different provinces. FW production showed a strong positive correlation with population (p < 0.01), GDP (p < 0.01), OMAP (p < 0.01) and GOVFFAHF (p < 0.01). Thus, more FW was generated in areas with higher living standards and a higher population density due to the higher consumption of major agricultural products (e.g. grains, vegetables, fruits and meat), of which the waste could be used to contribute to the production of FW. In addition, as shown in **Fig. 1B** and **Fig. 1C**, the GDP and OMAP of the 31 provinces of mainland China and their FW generation can be used to predict FW production by a power function with high regression coefficients, while no significant relationship could be determined for both GDP per capita and annual DPI.

$$FW = 3898\ GDP^{0.799}\ (R^2 = 0.805) \tag{2}$$

$$FW = 5.044\ OMAP^{0.720}\ (R^2 = 0.702) \tag{3}$$

where the unit of both *OMAP* and *FW* is ton, and the unit of *GDP* is billion Yuan.

On the other hand, FW arises within households and from the hospitality and food service, food manufacture, retail and wholesale sectors. It is estimated that FW comes mainly from households (47%) and food manufacturing (26%) in the UK (Parry et al., 2015), in comparison with 63% for households in Seoul, Korea (Government, 2016). It has also been reported that food losses were explored in relation to the supply chain characteristics and dietary intake, where the proportion of food not consumed within developing and developed nations were found to be similar (Bond et al., 2013). In addition, the major food losses and waste may be due to both inadequacies in infrastructure and overconsumption (Parfitt and Barthel, 2011). Previous research (Liu et al., 2013) has reported that behaviour change is a key factor in saving food, through identifying incentives to compel people to order an ‘appropriate amount’ of food and storing remaining food of appropriate quality for later use if it cannot be eaten. Therefore, raising public awareness of source reduction and separation of FW is required immediately (e.g. developing planning habits for producing and buying food; and a reduced focus on lavish and extravagant living).

3.2. Processes for FW treatment capacity

The treatment capacity of FW treatment facilities increased continuously. In 2012, the capacity was 8,200 tons per day, which increased to 11,600 tons per day in 2013 to 13,100 tons per day in 2014. Besides, 35 other facilities were under construction with a total capacity of 6,800 tons per day. Meanwhile, another 40 facilities (with total capacity of 6,600 tons per day) had already achieved official approval and their construction will be carried out after a feasibility analysis and project design (Bi et al., 2016). The total FW treatment capacity could reach 21,500 tons per day by the end of 2015, which would reach 32,907 tons per day by the end of 2018. However, this would only account for only 14.5% of total FW generated. Bi et al. (Bi et al., 2016) and Wei et al. (Wei et al., 2016) found that the total capacity varied significantly between different provinces (200 to 1,600 tons per day), while the average capacity of a single facility showed little variation (100 to 300 tons per day).

When compared with the designed capacity in the Chinese 12th five-year plan, only 48.76% and 74.62% of the required facilities and capacity have been completed, and there is also still a capacity gap of about 8,000 tons per day. The central area of China has achieved more than required in the 12th five-year plan (114%), followed by Western China (88.46%), while less than 60% of the requirements were fulfilled for Northeastern and Eastern China, respectively. In addition, only 23.39% of FW generated could be treated by existing facilities in Western China, followed by the Eastern coastal provinces with an average of 18.25%. The other two economic regions showed similar treatment percentages (14 – 15%). Therefore, the efficient operation of existing facilities, as well as the establishment of new facilities, is required to meet the enormous FW treatment requirements in China.

It should be noted that the designed capacity in the 12th five-year plan only accounted for 19.50% of FW production predicted in this study. Although completed

FW facilities are in operation, under-capacity is a bottleneck for the current pilot projects due to low collection capacities. De Clercq et al. found that actual treatment in a pilot project located in Beijing is only about 27% of the design capacity (150 t/d) (De Clercq et al., 2016). This is due to the slow progress of separating of FW from MSW at source in China. It suggested that the FW treatment facilities in Central China, in particular, may be ineffectively constructed and underutilized due to a low economic development and insufficient management experience. Therefore, capacity in central China needs to be enhanced and more funds invested in facilities by the Chinese government and local governments.

Moreover, based on estimated FW production in 2015, considering no major variations in FW generation, about 40% of FW generated could be treated by the end of 2020. The facilities in Eastern China are predicted to deal with 46.20% of total FW generated. A treatment ratio of 41% may be achieved in Northeastern and Western China, while the Central China has the lowest predicted treatment rate (27.88%). It should be mentioned that as a whole, China has made considerable development and improvement regarding the use of FW.

3.3. Characteristics of FW

Characteristic data on FW in China is obtained mainly from the literature, and ultimate analysis and proximate analyses of 80 types of FW as shown in **Fig. 2**.

Fig. 2

3.3.1. Physical characteristics

The TS and VS content in FW indicated high moisture content and high proportion of degradable organics (**Fig.** 2). pH values ranged from 3.55 to 7.33 with a mean value of 5.32 ± 0.97, showing a broad scope. An appropriate range of initial pH values for feedstocks needs to be guaranteed, especially for biological treatment facilities as a low pH can easily cause a low pH phase at the start of the process, and slow decomposition can occur during prolonged low pH conditions. This is a common problem for FW composting (Sundberg and Jönsson, 2008). Therefore, an initial pH adjustment through the addition of other waste as a buffer against organic acids produced during early stages of composting and AD may be beneficial to stablise composting and AD processes, thus helping to maintain pH within an appropriate range.

3.3.2. Chemical characteristics

Rice and pasta are two main staples of Chinese diet which contribute to the high carbohydrate contents in FW (22.4 – 70.2%). The amount of meat consumed in different regions varies enormously with economic and geographical differences, and therefore, the ether extract content due to different foods (e.g. pork, beef, lamb, and poultry) also varies significantly, ranging from 2% to 37% with a mean value of 19% ± 9% (dry basis). Previous research has been conducted on the role of carbohydrates, proteins, and lipids in anaerobic digestion and aerobic composting to identify the impact on performance and kinetic parameters during biodegradation of FW (Astals et al., 2014; Chang and Hsu, 2008; Dioha et al., 2013; Kawai et al., 2014; Li et al., 2017). For anaerobic digestion, synergistic effects improved process kinetics without a significant change in biodegradability (Astals et al., 2014). For composting process, substrates with a higher protein content demonstrated faster bacteria growth and consumption of acids consuming, while substrate containing high fat content slowly produced acid and CO_2 (Chang and Hsu, 2008). Therefore, it is feasible that adjusting mixing ratios of carbohydrate, protein and lipid are applied by blending FW with other organics to favor positive interactions, relieve inhibitions or toxic effects, promote the production of outputs (e.g. biogas, fertilizer), and decrease pollution. (Ma et al., 2017).

3.3.3. Biological characteristics

Macronutrients (i.e. protein, carbohydrate, and lipid) and nutrient elements (i.e. N, P, K) within the feedstock are essential for microbial growth, while C and N govern the speed and extent of the bioconversion process. As shown in **Fig.** 2, the N content of FW ranged from 0.8% to 30.3% in comparison with 30.3 – 75.0 % for C. The mean values for C and N (dry weight basis) in FW were 47% ±9% and 3% ±5%, respectively. As for C/N ratios, no great variation could be observed with an average value of 20 ±9 although major variability in carbohydrate, ether extract, and C content in FW were observed.

C/N ratios were typically considered as an important factor affecting the biodegradation process and a ratio of 25 to 30:1 is generally accepted as an ideal range for composting and AD processes (Dioha et al., 2013; Tompkins, 2005). Higher C/N ratios lead to insufficient nitrogen for microbial populations and slow processing of FW, while lower ratios can cause adverse effects, such as odor problems as the excess N is given off as ammonia. Compared with other organics, such as sewage sludge, FW in China presents higher C/N ratios, and therefore, wastes with a low organics content and C/N ratios (e.g. cattle manure, sewage sludge) may be co-treated with FW to increase the energy output (such as from methane production via co-digestion and fertilizer effect via co-composting) and compensate the rapid acidification and subsequent abundant volatile fatty acids (VFA) content.

4. FW treatment and disposal in China

Various FW treatment technologies are being used in China dependent on the capacity of the facility and desired final products (Fig. 3). The main process includes pretreatment (e.g. impurity sorting, crushing and thermal hydrolysis), a main waste treatment stage (e.g. AD, composting and thermal drying), and product post-processing (e.g. biodiesel, heat, electricity, fertilizer and feed additives).

4.1. Pretreatment techniques

Pretreatments are applied mainly to separate non-biological impurities (e.g. bones, plastics, and metals) from FW and enhance the stabilization of the FW by promoting the biodegradative properties (e.g. thermal pretreatment (Li et al., 2016)).

It should be mentioned that in many developed countries, such as Germany (Mühle et al., 2010), FW sorting is required. Although, source separation of MSW has been introduced in some prosperous cities in China, such as Beijing and Hangzhou, both classification of the waste and compliance are of low quality and this activity is not well-established in China (Zhang et al., 2010). FW, especially waste generated in household kitchens, are often mixed with MSW. In future developments, source separation should be carried out to reduce impurities and guarantee the quality of FW.

The inefficient source separation system of FW makes the recycling and biological reuse of FW (especially from kitchens) ineffective in China. FW generated by households is typically mixed and disposed of with MSW in landfills and incinerators, accounting for 60-78% of waste disposed of by these methods (Raninger, 2009; Zhang et al., 2010). However, due to the high moisture and organic matter content of FW, neither landfilling nor incineration is an environmentally benign and economically efficient method for the ultimate disposal of FW (Kalia, 2016). Minimizing air, soil, and groundwater pollution associated with landfills has already been realized in countries such as Germany through the implementation of the ‘Technical Instructions on Municipal Solid Waste’ in 2005 (Siedlungsabfall, 1993). This action should also be taken in China.

Thermal pretreatment (TP) is usually applied after pretreatment to achieve the effects of sterilization (Chen et al., 2015), homogenization, and solubilization of organic matters so that subsequent biological processes can be enhanced (Jin et al., 2016). It can also facilitate the oil separation and enhance oil extraction (Li et al., 2016). It is required by Technical Code for Food Waste Treatment (CJJ 184–2012) that thermal pretreatment applied to FW as a pretreatment process is operated between a temperature range of 95 to 120 ℃, with the duration being not less than 20 min. Previous research includes comprehensive studies of the effects of different treatment temperatures (55 – 160 ℃) and durations (15 –120 min) on the organic solubilization of FW and subsequent AD efficiency. These studies concluded that thermal pretreatment has varying impacts on the subsequent use of FW byproducts and temperatures best not exceed 120 °C (Jin et al., 2016). In addition, other research included a sustainability assessment of pretreatment methods with the aim of enhancing the organic fraction of MSW (Ariunbaatar et al., 2014). They show that thermal pretreatment at low temperatures (less than 110 °C) is the most sustainable method for enhancing AD processes, followed by conventional biological methods and mechanical pretreatment. Chemical, thermochemical, or thermal pretreatment methods at high temperatures (higher than 110 °C) can result in a higher enhancement of the AD process compared to untreated substrates. However, the costs and environmental considerations of high-temperature methods make them less desirable.

Three-phase separation is an essential process for facilitating the use of split waste phases, such as a liquid phase for AD, a solid phase for fertilizer and an oil phase for biodiesel. Thermal pretreatment may be more effective than other pretreatment methods for enhancing the efficiency of AD, oil-liquid separation efficiency, and the sterilization rate (Jin et al., 2016; Li et al., 2016).

After above pretreatment stages, the main FW treatment processes are applied. **Fig. 4** shows the current state of FW technical routes (TR), and TR3 (AD) and TR6 (composting) are the two most commonly used routes used by existing FW treatment plants in China. **Fig. 3** **Fig. 4**

4.2. Anaerobic digestion

4.2.1. Number of facilities

AD has been widely been applied in the European Union and many other developed Asian countries since 2006 (Ma et al., 2011). In China, AD is the most commonly used approach in terms of number of facilities and the overall capacity of FW treatment facilities (**Fig.** 4A), accounting for 76.1% of all treatment capacities (as at September 2015) (Wei et al., 2016). As shown in **Fig.** 4B, 54.1% of AD facilities have a treatment capacity higher than 200 t/d, while only 1.6% of these facilities had a treatment capacity lower than 100 t/d (**Fig.** 4B).

4.2.2. Operating parameters

With regards to the digestion temperature, a range of advantages associated with thermophilic digestion have been reported including faster reaction rates (Sanchez et al., 2001), more biogas production (El-Mashad et al., 2004), less inhibition by ammonia accumulation (Gallert et al., 1998), higher rates of pathogen destruction (Kim et al., 2006), and improved solid separation (Kaparaju and Angelidaki, 2008) in comparison to the mesophilic digestion. However, thermophilic processes are more sensitive to changes to environmental conditions than mesophilic process (De la Rubia et al., 2006; Kim et al., 2002); therefore, mesophilic digestion is more commonly used due to a higher overall solubilization rate (Komemoto et al., 2009).

Additionally, feedstock characteristics and process configuration are two major factors affecting the performance of AD for FW (Molino et al., 2013). Low methane yields and process instability are two of the main problems encountered when using AD and research has usually attributed this to a high protein content and ether extract due to toxic effects from free ammonia (NH_3) (Yenigün and Demirel, 2013) and long-chain fatty acids (LCFA) (Palatsi et al., 2010)(Rinzema et al., 1989). Previous work has reported that most anaerobic digesters do not function effectively due to technical failures, incorrect operation, or poor management regulation (Müller, 2007; Xu et al., 2017). Therefore, AD of FW is normally run with low organic loading rates or co-digestion of waste with low nitrogen and lipid content (e.g. sewage sludge or MSW) to overcome these problems with the concomitants benefit of increasing the biogas yield (Pham et al., 2015) and buffer capacity (Zhang et al., 2014). It was reported that co-digestion with animal manure and sewage sludge are practical options (Xu et al., 2017). However, other research has reported that two-stage digestion may attain higher organic loading rates (OLR), and higher methane generation that is less vulnerable to fluctuations in the OLR, than a single stage digestion process (Kiran et al., 2014; Ren et al., 2017). In reality, single-stage anaerobic digesters with continuously stirred tank reactors (CSTR) have mainly been applied in Chinese FW treatment plants with AD. It should also be noted that for AD (TR3 in Fig. 3), all liquid phases after three-phase separation are sent to the digester at mesophilic temperatures (approximately 35 to 37 ℃), and only a few plants utilized the liquid phase and some of the solid phase for digestion. This results in a long hydraulic retention time, generally in the range of 20 – 40 days (Pham et al., 2015). In addition, there may be some variation in methane yield with the same capacity and technical routes due to differences in the organic composition of the FW, ranging from 119 to 780 mL/g VS with a VS reduction of 80–90% as reported in previous studies (De Clercq et al., 2016; Kim et al., 2006; Shahriari et al., 2013; Zhang et al., 2013).

4.2.3. Utilization of biogas

Biogas is typically used to produce energy through different conversion systems (e.g. electrical, heat or transportation fuels) after the removal of undesirable compounds or contaminants (e.g. hydrogen sulfide, ammonia, and siloxanes) (Abbasi et al., 2012). In developed countries, there are financial instruments available to stimulate and support electricity and heat production from renewable sources, such as in the UK (e.g. the Renewable Heat Incentive and Feed in Tariff and Enhanced Capital Allowance)[**]. Besides this, Evangelisti et al. (Evangelisti et al., 2014) performed a life cycle analysis (LCA) with a sensitivity analysis and reported that maximizing the electricity produced by combined heat and power units fuelled by biogas may be one key factor affecting the development and deployment of future AD plants. It was estimated that 847 kWh of bioenergy may be achieved if one ton of FW was treated by AD in China (Dung et al., 2014). For 16,150 tons of FW per day treated by AD in China, the potential bioenergy yield could be about 14 GWh.

However, biogas is currently primarily used to generate heat for internal use in FW treatment plants in China, and there is currently no financial support mechanisms applied to AD in China. Since electricity is a more valuable product in terms of environmental benefit, the utilization of biogas generated from these FW treatment plants in China may facilitate gradual transition from combined heat and power to maximizing electricity production.

4.2.4. Treatment and use of digestate

Digestate comprises microbial biomass and semi-degraded organics and inorganics. Nutrients present in the digestate include macro nutrients such as nitrogen,

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[**] The Official Information Portal on Anaerobic Digestion. http://www.biogas-info.co.uk/about/incentives/

phosphorus, potassium, calcium, and magnesium; and micro nutrients or trace elements such as boron, zinc, iron, manganese, molybdenum, nickel, and boron. This makes digestate a valuable organic amendment or organic fertilizer (Nkoa, 2014) with a wider utilization range and better environmental and economic benefits than chemical fertilizers (Lukehurst et al., 2010; Owamah et al., 2014). Compared with raw slurry, digestate has lower odors and percolates more quickly into the soil with a lower risk of odor pollution during and after spreading. However, due to the volatile nature of the nitrogen in ammonia, the storage and application of composted digestate need to be carefully controlled to prevent negative impacts on the environment (Owamah et al., 2014). Trailing hoses and trailing-shoes injectors are suitable devices for improved application of digestates as a biofertilizer, with less surface area exposed to air and reduced contact with the topsoil compared to splash plate spreading (Lukehurst et al., 2010).

As for TR3 in China (**Fig**. 3), only the liquid phase from the FW is normally fed into the digester, and the AD process is similar to that for sewage but with a higher organic loading. Thus, little solid digestate is generated after digestion. Currently, the liquid digestate is treated via a wastewater treatment system and discharged after reaching an appropriate standard (Integrated Wastewater Discharge Standard (GB 8978-1996)). When liquid digestate is used as a fertilizer, the quality should refer to Standard of Water-soluble Fertilizers containing Humic-acids (NY 1106-2010). Some FW treatment facilities use both the liquid phase and minor amounts of solid phase FW as feedstock for AD; in this case, digestate separation is applied (e.g. dehydration) before liquid digestate is used as fertilizer.

The literature suggests that at present (Möller and Müller, 2012; Nkoa, 2014; Teglia et al., 2011), the effective use of digestate from AD of FW as an organic amendment and fertilizer is still in the research and development phase. None of the technologies developed for digestate processing and nutrient recovery (e.g. phosphorus precipitation and crystallization, ammonia stripping and absorption, acidic air scrubbing, biomass production and harvesting) (Vaneeckhaute et al., 2017) are currently being considered for widespread application in China.

Agricultural benefits and environmental risks are two of the main considerations regarding the reuse of digestate. The quantity and quality of the digestate are strongly related to the technical routes available, as well as the characteristics of the feedstock. Digestate also may occasionally contain heavy metals such as lead, chromium, cadmium, and mercury, and these can vary between batches from the same digester and even within the same batch (Lukehurst et al., 2010). Therefore, the quality management of digestate, involving permits and quality control standards, is proposed to ensure the safety and beneficial value of digestates when used as fertilizers, soil conditioners, or as a growing medium. The storage and application of the digestate must comply with codes of good agricultural practice and follow national guidelines and legislation.

4.3. Animal feed

4.3.1. Numbers of facilities

FW can be used as an animal feed because of the high energy content generated from the oxidation of organic compounds in the feed (e.g. carbohydrates, lipids, and proteins) (Lin et al., 2011). There are several methods for converting FW to an animal feed, such as boiling to produce a feed; producing a dry feed by dehydration, drying, disinfection, and crushing in sequence; and biological treatment (Chen et al., 2014). For dry pig feed, a South Korean law requires that FW must be heated to a core temperature higher than 80 °C for a minimum of 30 min (National Institute Of Environmental Research. Ministry Of Environment, 2012), compared to 100 °C for 60 min for the EU (Stuart, 2009). For wet pig feed, FW should be dehydrated and heat-treated to 100 °C for sterilization (Salemdeeb et al., 2017). As shown in **Fig. 4A**, there are only six animal feed facilities with a capacity of 700 tons per day, accounting for only 3.24% of total treatment capacity in China. This ratio is much lower than that of Japan (35.9%) and South Korea (42.5%) (Salemdeeb et al., 2017). This technical route was only applied for the first batch of pilot projects, before AD and composting became the predominant technical routes in later projects.

4.3.2. Concerns of animal feed

As an agricultural country, China has a high demand for animal feed and this could be an effective reuse method for FW through its production. However, due to the complex sources and composition of FW, there is the possibility that raw feed materials may introduce potential biological security hazards, such as homologous problems, pathogens, heavy metals and organic pollutants (Westendorf, 2000). Therefore, the effect on product safety of the FW feed is a key factor limiting the development of an industrial supply chain of animal feed from FW (Chen et al., 2014).

Previous research has systematically compared FW-derived animal feeds produced by three typical methods in China (fermentation, dry-heat treatment, and combined hydrothermal treatment and fermentation) focusing on the nutrient content, the presence of bovine- or sheep-derived materials, microbiological indices, and chemical contaminant indices. It was suggested that FW-derived animal feed is an adequate alternative for use in animal diets; however, the feeding methods may need to be changed for different qualities of feed because the presence of bovine- and sheep-derived materials or certain chemical contaminants may not meet European Union (EU) standards, such as Regulation (EC) No. 1069/2009 (Chen et al., 2015). It should be noted that EU guidelines state that FW should preferentially be used as animal feed. However, most FW recycled through this practice is currently illegal due to bio-safety concerns (Salemdeeb et al., 2017). Besides this, after a comparison of the environmental and health impacts of four different technologies for FW processing (including two technologies from South Korea for animal feed production (wet and dry pig feeds) and two UK disposal technologies (AD and composting)), it was suggested that the use of FW as a pig feed may offer environmental and public health benefits; and that support from policy makers, the public, and the pig industry is required (Salemdeeb et al., 2017). Other research estimated that recycling FW as pig feed at similar rates to nations such as Japan and South Korea may provide enough feed to support production for 20% of the EU market while reducing the land use associated with EU pork by 1.8 million hectares (Zu Ermgassen et al., 2016).

4.3.3. Suggestions for feed application

In order to enhance the potential use of FW as animal feed in China, the following solutions are suggested based on the current situation of waste management: a) required source separation, followed by separate transport and treatment over time. In this case, the classification and a model for timely collection would avoid the acidification and decay of FW, thus ensuring improving quality from the source; b) disinfection pretreatment, such as thermal pretreatment, to render FW safe (Li et al., 2016), should be considered to guarantee quality feed production (Jin et al., 2012); c) variability in dry matter, protein, ether extract, and energy content can limit the incorporation of FW as a feed additive for livestock and companion animal feeds (Westendorf, 2000); d) compared with the tight regulations issued by EU and US (such as Regulation ((EC) No. 1069/2009) (Chen et al., 2015) and NRC (1998)), the Chinese government needs to strictly restrict the use of FW as an animal feed by licensing mechanisms linked to regulations, such as GB/T 5915-2008.

4.4. FW composting

4.4.1. Number of facilities

FW is suitable for composting due to its high organic matter and minimal concern about heavy metals and pathogens. In addition, compost can be used as a fertilizer, applied to the soil to increase carbon storage capacity, and reduce GHG emissions (Cerda et al., 2017). FW composting has attracted considerable attention in recent years in China, especially when considering the limitations placed on animal feeds by the Chinese government, and the current capacity to divert poor quality or inadequately separated FW to composting or AD in China. This may be another reason for the high percentage FW being used as a fertilizer rather than animal feed.

Three composting routes (17%) are mainly applied in China (**Fig. 4A**), including solid phase FW composting with liquid phase AD (3.3%), aerobic composting (5.2%), and rapid aerobic composting (8.9%).

4.4.2. Concerns related fertilizer use

Converting FW to fertilizer can reduce the need for chemical fertilizer and soil bioremediation (Cerda et al., 2017). However, FW composting processes face several issues that influence the process efficiency and product quality. They are as follows. a) A long duration is required to complete the composting process (Ab Muttalib et al., 2016), such as three to four months for a small-scale composting operation using windrows (Awasthi et al., 2014). b) issues with acidity and odor emissions are likely when low molecular weight organic acids are generated (Wang et al., 2018), resulting in a decrease in pH and an inhibition of microbiological activity (Sundberg and Jönsson, 2005) due to the specific characteristics of FW (e.g. high moisture, acidity, high oil content and high salinity) (Chan et al., 2016; Sundberg, 2005). c) Heavy metal contamination is possible, causing soil pollution, which eventually accumulates in the human body via the food chain (Ab Muttalib et al., 2016). d) Markets are difficult to access for composting facilities, and revenue often doesnot offset operating costs as a result (Murphy and Power, 2006).

On the other hand, since China covers a large area, the characteristics of FW from each of these four regions will vary significantly, thereby affecting the composting process (Chang and Hsu, 2008). For example, a high protein content in the FW may produce more CO_2, reach higher temperatures, and result in higher final pH values, while high-fat content in the substrate will slow down the production of acid and CO_2 (Chang and Hsu, 2008).

4.4.3. Suggestion for fertilizer application

In Western China, fertilizer produced from FW is used to improve contaminated and compacted soil (especially in the Northwestern regions). As for Northern China, the salt content in FW is usually very high, presenting a challenge for process control. Although a number of simulation approaches have been proposed to help understand and optimize composting process mechanisms, they usually are not effective in predicting the dynamics or complexity of FW composting accurately (Li et al., 2013). Thus, composting processes need to be well controlled and designed in an effective and efficient way. Therefore, the fact that source-separated FW in China can be converted to fertilizer with a high process efficiency and good product quality is promising and deserves more attention.

4.5. Other new treatment techniques

In addition, other new technologies for FW treatment include processing by the larvae of black soldier flies (BSFs), *Hermetiaillucens* (Diptera: Stratiomyidae), which can convert organic waste (e.g. MSW (Diener et al., 2011), pig manure (Newton et al., 2005), and restaurant waste(Zheng et al., 2012)) into valuable products (e.g. versatile prepupae for animal feedstuff (Diener et al., 2011) and biodiesel production (Li et al., 2011)). Due to China having limited crop land and the world’s largest population, it is important for the country to develop non-food based feedstocks for biodiesel production instead of only oil produced from crops for biodiesel production (Li et al., 2011). Therefore, converting FW to biodiesel via BSF larvae may contribute to reducing and reusing FW for some applications.

During the treatment of FW, BSFs can also be harvested as an animal feed for poultry, pigs, ducks, birds, and fish. In addition, the fuel properties BSF-based biodiesel, such as the density, viscosity, and cetane number, are comparable to those for rapeseed oil-based biodiesel (Li et al., 2011). The literature reports an average prepupae production of 252 g/m^2/d (wet weight) and a waste reduction ranging from 65.5% to 78.9% with BSF treatment of MSW (Diener et al., 2011; Diener et al., 2009).

Usually, this method is used in FW treatment plants with small capacities (lower than 100 tons per day). In addition, several factors strongly influence the larval yield and waste reduction capacity, including a) lack of fertile eggs and high larval mortality due to the presence of heavy metals (Diener et al., 2011); and b) limited access to food from stagnating liquid (Diener et al., 2011). Previous research has confirmed the significant potential of BSFs for organic waste treatment in low- and middle-income countries(Diener et al., 2011), and these studies have also pointed out the knowledge gaps pertaining to biological larvae requirements such as the egg hatching rate, moisture tolerance, and process design (drainage and rearing facilities) to be tackled in future research (Diener et al., 2011; Diener et al., 2011).

4.6. FW pilot projects

In China, the capacity of these 100 pilots ranged from 100 to 600 t/d, and the key process for these projects was anaerobic digestion with aerobic composting, which accounted for approximately 56% of the capacity. One ton of FW could potentially produce 21–105 m^3 biogas, which is lower than the value (about 420 m^3) estimated by Lou et al. (2013) (Lou et al., 2013). This is mainly due to the digestion pattern of AD in China: only liquid phase FW after three-phase separation is usually fed into the digester (Section 4.2), and as such, less of the organic matters in FW is converted into biogas.

Since the scale of economy, key techniques, and treatment capacities differ, the amounts of investment in these projects varied. Regarding geographic distribution (Section 3.1), more FW is generated in the eastern part of China than in western regions, and more projects are located therein as well. Therefore, FW treatment plants and companies pay more attention to FW treatment and disposal in this area.

5. Discussion

5.1. Key bottlenecks of pilot projects

5.1.1. Insufficient treatment capacity

Faced with this high treatment gap and potential pollution related to FW, the following activities are suggested at the very least.

First, both businesses and individuals need to minimize the flow of wasted food. Source reduction would bring numerous benefits, such as saving the energy associated with growing, preparing and transporting food; reducing GHG emissions; and saving money through the more efficient handling, preparation, and storage of food (Gunders, 2012). Secondly, although local governments and enterprises have increased their focus on the collection of FW, the corresponding facilities, schemes and source separation awareness of FW collection and transportation are incipient and further improvements are still needed. Moreover, FW treatment in China still faces inadequate administrative measures for separation and collection as well as budget allocations for FW management. Although some specific and effective regulations have also been promulgated by local governments to enhance FW management, appropriate technical codes for the separation and collection of FW and other supporting regulations have not been well promulgated and they often lack funds to support the launch of FW management activities. In addition, only some megacities in China with a high GDP (e.g. Beijing, Shanghai) implement source separation of FW or are still exploring feasible strategies to achieve this. For these cities, impurities in FW still account for about 10 to 15% of FW collected, thus resulting in a large burden and high cost at the pretreatment stage. Therefore, targeted collection facilities need to be set up, while the infrastructure and budgets to do this also need to be guaranteed. In addition to the complete legislative frameworks, sufficient and proper education programs to improve FW's separation and collection rates, participation by the private sector in recycling and FW diversion activities, and proper funding to improve their FW services should be considered as well. It was reported that Japan's Food Waste Recycling Law and related initiatives have made progress in encouraging recycling and waste minimization among food business industries since 2001, while some incentives were developed by the Japanese government to promote the FW recycling, for instance, a certification system was introduced for animal feed (called “Eco-feed”) and for fertilizer and the agricultural products (“Food Recycle Mark” certification) (Liu et al., 2016).

To provide adequate FW treatment capacity, new treatment facilities need to be designed and constructed, and thus, additional financial support is required from the Chinese government, local governments and non-governmental organizations. When carrying out the design and construction, it will be more reasonable to make adjustments based on individual local situations, such as the geographical distribution of catering enterprises, market potential for byproduct, FW generation, and FW characteristics. In addition, the design and implementation the conversion of FW from both new and existing facilities should ensure efficient operation.

5.1.2. Under-capacity operation

Although the total current capacity of existing FW treatment facilities can not meet the treatment requirements of FW generated in China, under capacity is also an issue for FW treatment plants (De Clercq et al., 2016). This can be ascribed to poor source separation and inefficient collection performance both in terms of quantity and quality. The classification of MSW and FW source separation have not been fully carried out in China where large population and food consumption limit the development of these activities. The concentration of FW in urban solid waste comprises the highest proportion (approximately 60%) of waste in China (Zhang et al., 2010).

On the other hand, FW treatment plants only have limited product income generation from byproducts (e.g. fertilizer, animal feed) and use biogas to provide heat for internal use to reduce the cost of heating systems. It has been reported that subsidies from the government have been used to support for FW processing in other contexts (Hu et al., 2012). Under-capacity can result in low biogas production and lower fertilizer production rate, thus, leading to the poor financial performance of FW treatment plants. According to a cost-benefit analysis of facilities with a capacity of 200 t /d or more, only if 58 to 60% of the total capacity was guaranteed each pilot could break even. Besides this, it was reported that few differences in either the operating time or processing cost were observed on the same processing line for treating different quantities of FW, resulting in a large disparity in resource outputs (e.g. product generation) and resource inputs (Wei et al., 2015). Moreover, the frequent start-up of processing equipment can lead to greater losses due to low collection rates of FW.

5.1.3. Lack of techniques for high-value application of products

For the two of the most popular technical routes for FW treatment in China, i.e. AD and composting, which constitute 93.5% of the total capacity of FW treatment, the further utilization of biogas and fertilizer still present immediate problems that need to be to be addressed. First, a gas grid to distribute biogas is not available in China and biomethane from the AD of FW is not easy to distribute for lowering CO_2 emissions from energy supplies through substituting waste heat. Besides this, as the large volume of digestate produced still presents a challenge for further disposal. Secondly, due to the lack of source separation of MSW, the quality of the FW collected even after pretreatment cannot be guaranteed. Besides, the high ether extract content may lead to the emission of GHG gas (e.g. CH_4) during the decomposition process while high salinity may cause damage, even at lower concentrations when applied to soil. In addition, the fertilizer produced from FW also competes with various chemical fertilizer and animal manure products, resulting in problems related to the operational parameters and investment in composting facilities (Thi et al., 2015).

Meanwhile, animal feed production is strictly regulated in terms of both quality and market access. A license from the Ministry of Agriculture is needed to operate an animal feed production site while planning permission from local authorities is required before a license can be issued. There are many stringent requirements for obtaining a license throughout the entire production process (e.g. process consistency, product quality). Furthermore, this license is tempory and is no longer issued for FW treatment facilities producing animal feed. Moreover, existing FW treatment plants are not familiar with biodiesel processing methods and the product quality of this approach can not yet justify the higher processing costs.

In addition, the development of process and quality control methods are two other challenges for FW treatment, including process monitoring and feedback controls, as well as inefficient product use (De Clercq et al., 2016). Further improvements are required, such as equipping appropriate management and personnel with measuring and monitoring equipment. The development of a management system for the entire FW treatment process (e.g. the discharge, collection, transportation, treatment and product utilization) is required. This may provide a standard basis for regulating the management and operation of the treatment plants and regulatory authorities (e.g. government departments, employers, contractors, employees and the public) and provide an effective means for preventing operational problems to guide effective resettlement planning, implementation, and follow-up.

5.2. Improvement of thermal pretreatment

Due to the various impacts of thermal pretreatment on subsequent split-phase utilization of FW (Li et al., 2016), further research needs to focused on the appropriate treatment temperature and duration of thermal hydrolysis to identify a reasonable degree of treatment and floating oil extraction ratio may result in higher biogas production and less inhibition caused by lipids. In addition, proper biodiesel production may be achieved, thus obtaining improved economic and environmental benefits.

It should be noted that the operating parameters for thermal pretreatment need to be optimized based on FW characteristics, pretreatment efficiency, and subsequent recycling methods. It is necessary to carry out an energy balance and economic analysis of the combined thermal pretreatment and subsequent resource utilization methods, including whether improved biomethane production can offset the energy costs for thermal pretreatment and how to harmonize the use of thermal pretreatment with subsequent processes such as thermophilic digestion.

5.3. Comparison of different treatment techniques

Appropriate capacity and reasonable technical routes for FW treatment facilities, accurate and complete data that reflects the actual operating situation is a premise for improved operation and efficient treatment. As to low FW generation and short transportation distance, on-site rapid aerobic composting via biochemical processing is suggested to reduce transportation costs, while about 95% of organic matter can be decomposed within 24 h, with the residues being used as fertilizer. For small-scale FW treatment plants (less than 50 t/d), centralized processing is the best choice and bio-protein feed and organic fertilizer can be obtained after anaerobic composting process through the construction of simple infrastructure and convenient management system as most collection and transportation processes can be avoided. For a capacity of 50 t/d for example, at a temperature range of 60 – 80 ^{o}C for 8 h, the processing cost is about 130 Yuan, while the total investment is about 20,500 thousand Yuan (Xing et al., 2006). Therefore, the above two options are especially applicable to small and medium-sized cities with a lower economic and management capacity. For large-scale and super large-scale FW treatment plants, based the capital investment per unit of waste treated can be reduced when the scale of a FW treatment plant exceeds a certain threshold, it is appropriate to use conventional biological treatment methods and with technical modifications such as co-generation and combined heat and power (CHP) approaches.

The selection of processing methods depends on multiple factors including energy efficiency, cost, land availability, financial support, market demand, and treatment capacity, etc. (Adhikari et al., 2006). China covers a large area and the generation of FW is different from place to place. Thus, for large cities with a large FW generation, large-scale and super large-scale scale FW treatment plants with centralized processing technologies are suggested, while composting with modified technologies are the best choices for regions located away from centralized treatment plants with a lower GDP, such as the use of BSFs for possible livestock feed and biodiesel production. In addition, FW biorefinery platform could valorize multiple biobased products sustainably and lead to the development of circular bioeconomy (Dahiya et al., 2017; Ren et al., 2017).

5.4. Further development

5.4.1. Management aspects

Administrative units should promulgate reasonable and comprehensive standards and regulations aimed at enhancing utilization of FW resources with diversified technical routes with careful consideration of FW characteristics, generation characteristics, and local market requirements.

FW use as a fertilizer is strongly supported by national policy. With the development of agricultural cooperation between ecological farms and livestock farm, the demand for compost will increase. To promote compost derived from FW, it is important to consider the balance of supply and demand between regions as the quantity of available animal manure varies across the country. In addition, policies are required to encourage the use of organic rather than chemical fertilizers.

Conversely, the diversion of FW for animal feed is emphasized in Japan and South Korea. This practice still faces many difficulties related to bio-safety concerns in China. With further strengthening of FW sorting processes, the production of animal feed from FW, especially for food producers, could offer environmental and economic benefits.China has a high demand for animal feeds, and the implementation of policies that are more flexible and enables the use of FW as a good quality animal feed is required. This may start with pilot projects in a minority of regions in China (such as those with high levels agriculture forestry, animal husbandry, and fishery). Meanwhile, support from policymakers, the public and animal industries is required.

5.4.2. Technical aspects

Prior to the discharge of FW, it is essential to raise public awareness of source reduction and source separation. Most FW can be avoided. The potential to reduce FW is reported to be as high as 75% in the UK (Parry et al., 2015), while source reduction is the priority action required by the Environmental Protection Agency in the US (EPA, 2014). In China, the highest food loss rate, defined as the ratio of lost or wasted food to the total amount of food production, is achieved in restaurants (19%) (Liu et al., 2013). During FW collection, actions need to be taken in China to enhance the quantity and quality of FW collected, including constructing a separated FW collection system to prevent leakages and odors from sewers, while FW generated in households should be diverted from MSW streams. During FW treatment processes, some countermeasures need to be taken including legislated pretreatment methods, diversified treatment capacities and technical routes, and the advanced use of end products. Basing on this, split-phase utilization after thermal pretreatment is recommended. Moreover, income is quite limited from single resource-based routes for FW treatment, and therefore, diversified technical process routes for FW treatment need to be optimized and combined. In addition, struvite precipitation, ammonia stripping and absorption using acidic air scrubber could be feasible options for nutrient recovery as marketable fertilizer commodities (Vaneeckhaute et al., 2017).

It should be noted that converting FW into pig feed could lead to lower environmental and health impacts than processing FW by composting or AD (Salemdeeb et al., 2017), which is the Chinese government's currently preferred option. Besides, characteristics of FW generated from different business categories, such as food manufacturers, food wholesalers, restaurant industry, and households are significantly different. Therefore, FW collected from different food-related business operators are suggested to be recycled according to their level of quality, classification, and complexity of compositions etc. FW source separation has different levels of difficulty, while suitable treatment methods are variable. It is easy to separate FW generated from food manufacturers and high-quality raw FW materials can be guaranteed. Therefore, considering product safety and high-value applications, FW from these categories should be used as feeds. FW from food wholesalers and restaurants has medium difficulty in source separation this can be used for producing fertilizer. Conversely, FW from households is suggested for methane fermentation due to difficulties in source separation. In addition, FW from food wholesalers, restaurants and households may be used to produce biogas via AD process.

5.4.3. Further research perspectives

Adequate and accurate information in terms of the current status of FW treatment and management such as FW characteristics, the distributions of FW generation, as well as state of the art treatment approaches is the basis for making appropriate decisions about FW treatment. Besides, it is necessary to carry out a comprehensive evaluation of current pilot projects in terms of their technical routes, performance parameters, development and implementation of regulations, operating modes, investment sources, economic benefits, quality, and market demand for these resource-oriented products.

Meanwhile, further research may focus on how and to what extent the variation of FW composition affects the entir treatment process, including a technical, environmental and economic analysis of different treatment technologies. This information based on a broad composition range and technical routes may help engineers design better systems for reducing and recycling FW and operators to optimize operating parameters. Then, data resources (e.g. FW production data, collection and treatment records, facility information, technological processes, and processing data) can be developed. Thus, information management processes may be realized as well as the developent of effective technical capability and more effective communication.

6. Conclusions

FW treatment capacity could increase to 40% in China by the end of 2020. Carbohydrates and lipids in FW exhibited large variations compared with proteins. No specific or detailed technical guidelines, standards or regulations for FW management exist in China. Pretreatment and three-phase (liquid solid and oil phase) separation are necessary and AD is the main technical route used. Higher FW generation and treatment capacity were achieved in the Eastern China with higher GDP and population. To overcome factors negatively impacting FW treatment, suggestions including source separation, pretreatment improvement, reasonable technical routes, targeted legislation and end product utilization are proposed.

E-supplementary data of this work can be found in online version of the paper.

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Figures

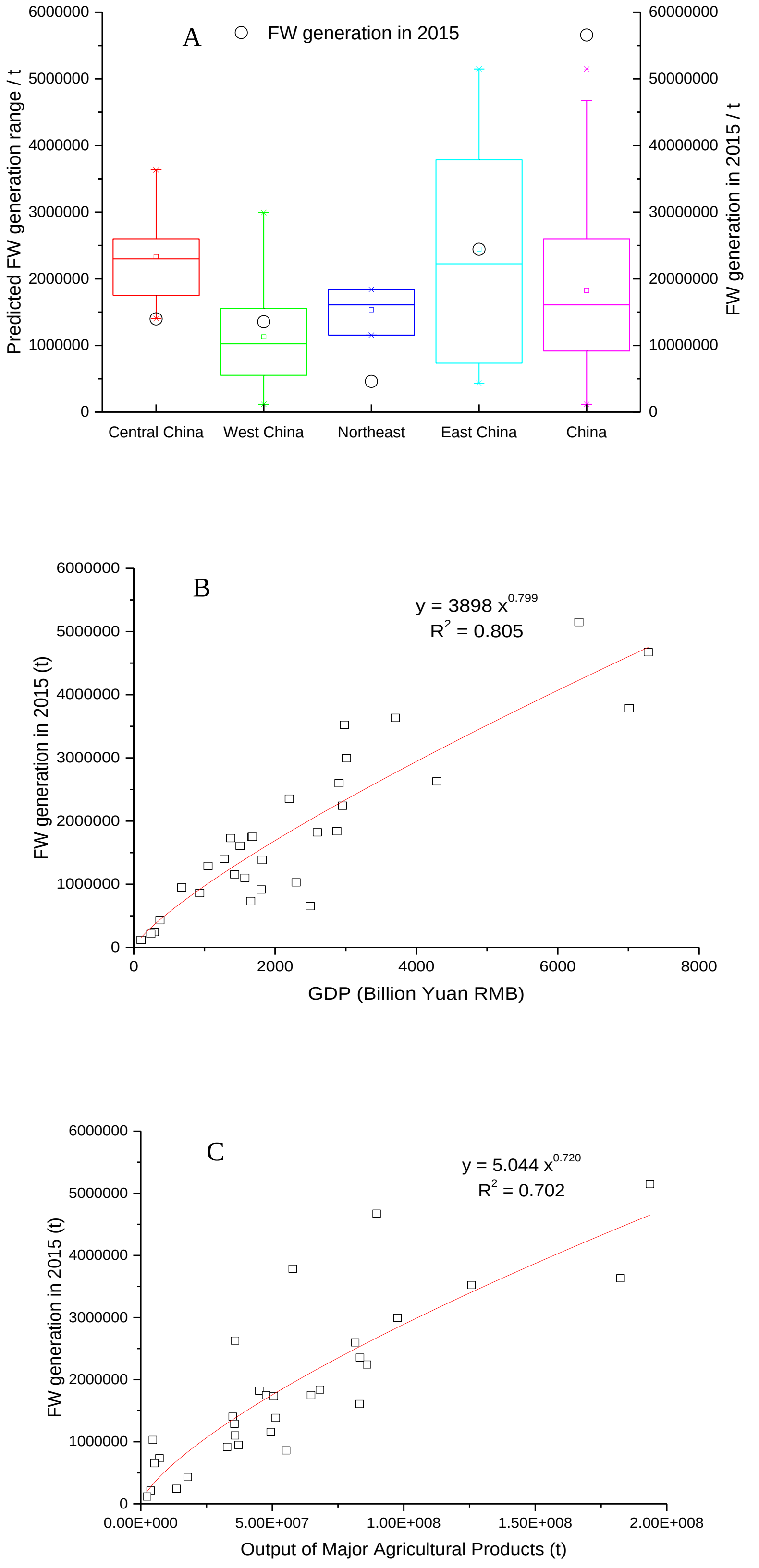

Fig. 1. FW generation in four regions of China in 2015(A), and the relationship between FW generation and GDP (B), OMAP (C).

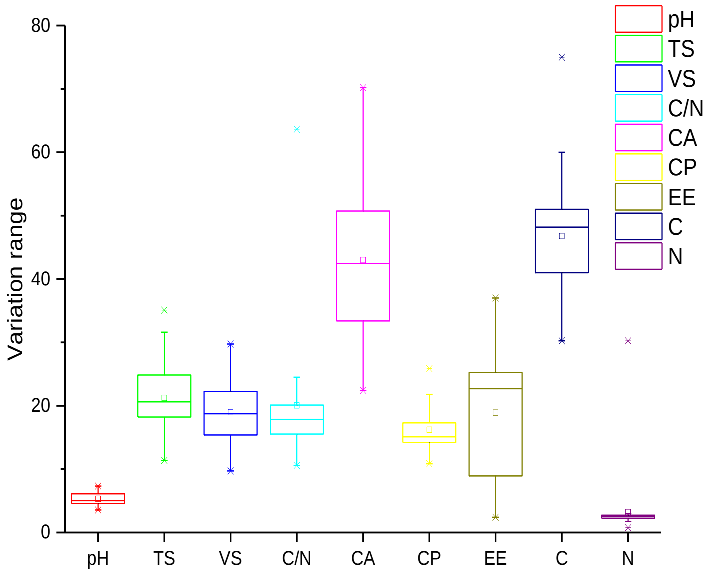

Fig. 2. FW characteristics in China (CA: carbohydrate, CP: protein, EE: ether extract).

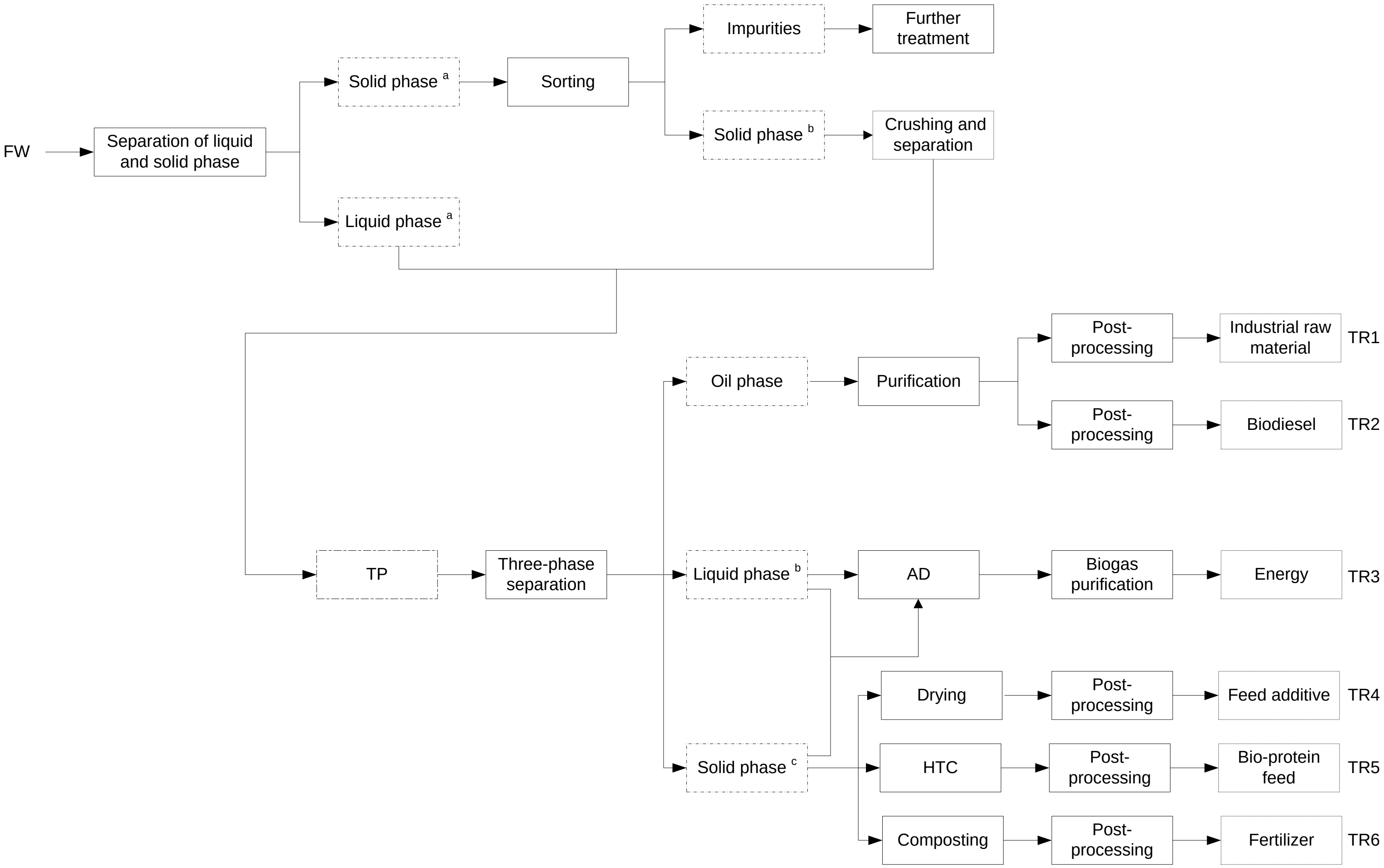

Fig. 3. Main technical routes of FW treatment in China.

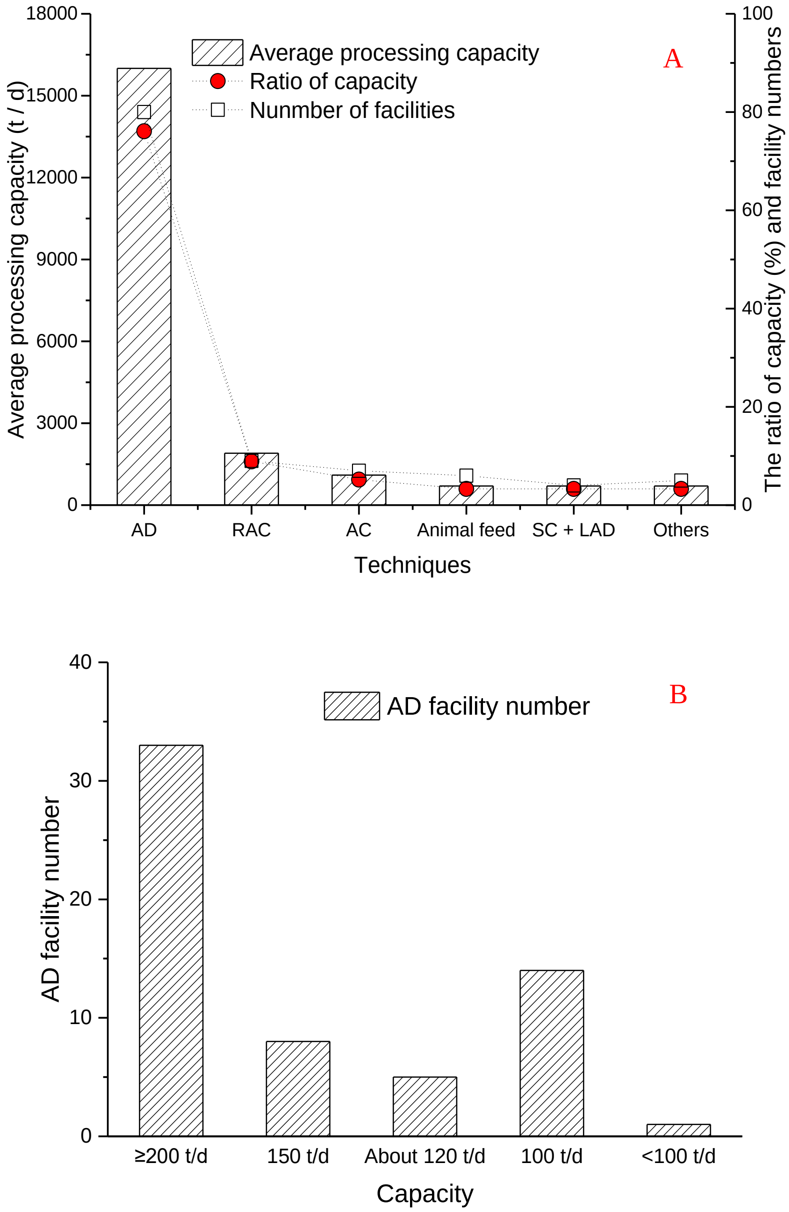

Fig. 4. State of FW treatment with different technical routes including current capacity and numbers of facilities (Wei et al., 2016)(A) (SC + LAD: solid phase FW composting with liquid phase anaerobic digestion; AC: aerobic composting; RAC: rapid aerobic composting), and the number of FW treatment facilities with different capacities using AD (B).