Life cycle assessment on food waste and its application in China

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Abstract. Food waste causes tremendous problems in terms of environment and economy, twined with big social influence, thus studies on food waste are essential and meanwhile very complicated. According to Food and Agriculture Organization of the United Nations (FAO), 1.3 billion ton/year of food are wasted globally, which has a total carbon footprint of 4.4 GtCO₂ eq per year with a cost of USD 411 billion. According to statistics, China has roughly 195 million tons food waste per year, which is huge. Life Cycle Assessment (LCA), which is an internationally standardized method by ISO for assessment of product and process, has been applied in food sectors to evaluate the different environmental influence, energy use etc. This paper analyzed some of the LCA application on the different parts of the food supply chain (production, post-harvest handling, the storage and transportation, processing, the retail, and consumption) where food waste is generated and on the food waste disposal stage, looked into what has been studied in the context of China, and gave recommendations for LCA application for Chinese food waste problems: 1) More application of LCA on food waste should be made on the early stage of the food cycle rather than just the kitchen waste; 2) Besides global warming potentials, other environmental influences should be studied more at the same time; 3) Food waste treatment can be studied using LCA broadly considering mixture with other substrates and using different recycling methods; 4) LCA based on a local context with local data/inventory are strongly needed; 5) further more detailed studies to support an elevated food waste management, such as food waste profile can be developed.

1. Introduction

“Hoeing the grass under the noonday sun, his sweat drips on the ground beneath”. The famous poetry “sympathy of farmers” of ancient China has called for action to not waste food for centuries. Now this topic is drawing global attention as United Nations set up a specific goal on food waste reduction (SDG 12.3): by 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.
Food waste (sometimes being called as food wastage, or food loss and waste, here in this text we all call it food waste) has so far not reached a consensus on its definition globally. The European project FUSIONS defined it as “any food, and inedible parts of food, removed from (lost to or diverted from ) the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)”, by Östergren et al. (2014)

Food waste occurs at all stages of the food supply chain, from the agricultural production, post-harvest handling, the storage and transportation, the processing, the retail (including wholesale, supermarket and fresh food market, etc.), consumption (home and restaurant). Food lost throughout the food supply and consumption chain is a big waste not only for food, but also for water, energy and land resources. This becomes a burden to environment, and also aggravated the food/nutrition security problems, especially for those poor and marginalized groups. According to FAO report in 2011, there are altogether 1.3 billion tons of food wasted every year, and around half of it is from developing countries. And according to Yang et al. (2012), the amount of food waste generated by China reaches 195 million tons per year. If so, it is more than 30% of the whole food waste from all developing countries.

A life cycle assessment (LCA) studies the environmental interventions and potential impacts throughout a product’s life (i.e., from cradle-to-grave) from obtaining of raw material then production, utilization and finally disposal. This is done by compiling an inventory of relevant system inputs/outputs (inventory analysis), evaluating the potential impacts of identified inputs /outputs (impact assessment), and interpreting the results (interpretation) in relation to the objectives of the study (which should be defined in the goal and scope definition in the beginning of the study). Initiated from the end of 1960s, Life Cycle Assessment methodology has been developed very quickly, especially in the 1990s, and reached a certain level of harmonization and standardization. It is considered to be an important tool for decision-making supporting and evaluating waste streams. It can help exhibiting the varied impacts on the environment from different parts of the system, and it can also assess alternative scenarios (technologies/systems). One of the main potential uses of life cycle assessment (LCA) in environmental management is for identifying improvement approaches for environment within a system in which complete supply chains are considered. Being applied in food waste assessment in various cases and studies, there is no doubt that LCA can contribute to the food waste issues. But to have a clearer picture of how and where LCA have been applied for studying and tackling food waste problems, this paper provides a general review of LCA application relevant to food waste, with a special attention to identify its focus on the different parts of the food supply chain, looks into what has been studied in the context of China, and then gives recommendations for LCA application on Chinese food waste problems.

2. LCA studies on food waste

Normally below environmental impacts categories are studied for applying LCA: global warming potential (GWP); eutrophication potential (EP); acidification potential (AP); photochemical ozone creation potential (POCP); ozone depletion potential (ODP); human toxicity potential (HTP); ecotoxicity potential (ETP); abiotic resource depletion (ARD); biotic resource depletion (BRD); reported energy (RE); land use (LU); biodiversity (BD); water use (WU). And Tukker et al (2006) concluded that food and drink was responsible for 20-50% of various environmental impacts of private consumption in the EU. Monier et al (2010) also gave ideas on average greenhouse gas emissions for food products in its different stages in the food supply chain. WRAP (WRAP, 2013a) and FAO (FAO, 2013) made calculations on greenhouse gas emissions from food waste.

2.1. LCA studies of food waste for partial/full stages of the food supply chain

Thomas Ohlsson (2004) brought forward the opinion that to avoid sub-optimization, food waste management should involve assessing the environmental impact of the whole food chain. Figure 1 illustrates the life cycle phases of food supply, consumption and disposal, where environmental
influences occur. LCA can summarize the emission and related to the major environmental concerns. Ohlsson identified that eutrophication, energy efficiency, phosphorus, toxicity and waste management are most relevant when it comes to food production chain. He left out one important category: global warming potential (GWP), which later have been studied by many other scholars.

![Figure 1. Life cycle phases in the whole food supply chain](image)

Single food items were being studied by many scholars. As Poritosh Roy et al. (2009) summarized in the review of LCA on some food products, industrial food such as bread, beer, tomato ketchup, other food categories like diary and meat, and several more food studies were studied tentatively since the end of 1990s until then, and LCA studies on packaging systems are illustrated. Inconsistencies among studies were pointed out, and choice of functional unit were emphasized, especially the application of multiple function units, which would help in better interpreting and understanding the environmental burden.

With the similar observation, that the single food product LCA has been studied extensively on major food items, Jennifer Davis et al. (2008) studied the environmental impacts (GWP, EP, AP, POCP and use of primary energy carriers and secondary energy) of complete meals (homemade and semi-prepared chicken meals) based on LCA, where improvement scenarios were constructed including: reduced fuel consumption in truck transport, reduced energy use in industry, reduced energy us in retail, reduced raw material wastage in industry, reduced consumer shopping frequency, reduced amount of food packaging, reduced household wastage and reduced energy use for household appliances. It takes into account all losses between farm and table.

EU realized the importance of food waste and its potential contribution to environment, thus has entrusted Bio Intelligence Service to study the life cycle environmental emissions from food waste for each sector (Manufacturing, Wholesale/Retail, Food Service/Catering, Households) for the whole EU27. The report applied the life cycle inventories from the LCA Food project database (for beef, pork and milk) and the ecoinvent 2.0 database (for corn, potato and wheat). It gave a rough environmental influence of food waste from EU 27 based on that food waste generated along the food supply chain would have accumulative environmental effects as it requires all the resources/energy needed further up in the chain (emission values for each stage on the supply chain were calculated based on literature review, mainly focusing on GWP, but a few other factors were chosen to be studied in some calculations). It did not distinguish the impacts of food according to food type.
Globally, FAO report (2013) provides an account of the environmental footprint of food wastage (i.e. both food loss and food waste) along the food supply chain for the whole food life cycle based on food balancing sheet (FBS), focusing on impacts on climate, water, land and bio-diversity. A model has been developed to answer two key questions: how big is the food wastage impacts on the environment in the world; and impacts, with respect to regions, commodities, and phases of the food supply chain involved—in order to identify “environmental hot spots” related to food waste. Organizations like UN Environment, WRI and WRAP have also been organizing studies using LCA on food industries /food waste analysis.

Methodologies studies in the context of food waste also exist. In the EU project FUSIONS report, Life Cycle Assessment (LCA) was used, which accounts emissions from cradle to grave considering different steps of the food supply chain. It tested two approaches: Bottom-up approach, starting from specific indicator products and ending with an extrapolation of results, and top-down approach, starting from greenhouse gas emissions on aggregated level over certain steps of the food supply chain and ending at results for emissions related to the total consumed and wasted food. Both approaches has a functional unit of 1 kg consumed food. System boundaries are from primary production, including agriculture, to recovery and disposal of food waste, not including the food valorization and conversion step (e.g. animal feed) because of lack of data. GWP are explored mainly, with AP and EP also looked into. The two methods were compared, and concluded that the top-down approach appears to offer a rapid way of approximating the GWP and regularly updated information is available from data sources. The bottom-up approach serves results on an indicator product level and from the perspective of the polluter pays principle, which can serve as a good basis to set targeted waste prevention activities.

To extend the LCA studies to cleaner production (including food product waste), etc., Rafael Laurenti et al. (2016) firstly tried to use available LCA data for examining quantities, types, sources and reasons of waste generated in the course of producing consumer goods (waste footprint concept was developed). And 3 types of food (chicken, beef, milk) were chosen for test calculation on their pre-consumer waste footprint. The paper proposed standardized data declaration on waste in life cycle assessment, with a separation into waste categories illustrating the implicit environmental and scale of significance of waste types and quantities (e.g. hazardous waste, inert waste, waste for recycling/incineration) and establishment of a common definition of waste throughout sectors and nations.

Focus on single stage in the food supply chain are also available. Michael Martin et al. (2016) compared the different food consumption scenarios for Sweden using LCA. The study scope is from agricultural production to the household purchase (food preparation/consumption and waste management were not included in the study). It compared the GWP, HTP, AP, EP, LU and BDP under 9 scenarios with different combination of food consumption (such as reduced meat consumption by 25%, local produced food increased by 10%, etc.), and found that a reduction in meat consumption led to potential impact reductions in nearly all impact categories. Local produced foods showed reduced environmental impacts compared to imported food in nearly all impact categories. It also found out the importance of studying more on imported and local food. And life cycle inventory data availability needs to be improved.

2.2. LCA of food waste disposal
Bernstad and la Cour Jansen (2011) compared different disposal methods of food waste (composting, anaerobic digestion and incineration) with LCA where whole chain, and they highlighted the importance of source-sorting, which is crucial for process efficiency.

Takeshi Matsuda et al. (2012) use LCA to analyze the household waste reduction activities in terms of greenhouse gas emissions. It designs tests using 3 treatment methods including incineration, anaerobic digestion with or without source separation, and source separation scenario alone considered 3 food reduction cases including preventing loss of edible food, draining moisture contents as well as home composting, all with waste reduction of 5%.
Finally, he reaches the conclusion that prevention of food losses enhanced by separate collecting led to a significant reduction in GHG emissions (although contributions of the 3 reduction activities to the waste reduction are unknown). Also, the units of the GHG emissions, kg CO2-eq/t should be avoided in favour of kg CO2-eq/(person-year) because the denominator of the former is affected by waste prevention while that of the latter is not. Assumptions like waste reduction rate needs to be verified. And in the study only the GHG emissions are addressed.

Gursel, A.P., et al. (2015) explored the environmental, mechanical, and durability properties of “green” concrete mixes with rice husk ash, and concluded with the suitable mix ratios for better resource utilization of rice husk in industries.

Ashiq Ahamed et al. (2016) studied the solid waste management (including food waste, paper and plastic generated per year from Thessaloniki city in Singapore) including incineration, bio-treatment and paper recycling.

Mattias Eriksson et al. (2017) compared the effect on greenhouse gas emissions and primary energy use of different food waste management scenarios in a Swedish city, where LCA was performed for four waste management scenarios (incineration anaerobic digestion, conversion and donation) using 5 food products (bananas, tomatoes, apples, orange and sweet peppers) from the fresh fruit and vegetables department in two supermarkets as examples when treated as individual waste streams. It is concluded that re-use scenarios had higher potential for environmental impact reduction compared with energy recovery scenarios. There is also another paper of same authors in 2015 using same methodologies to compare 6 waste management scenarios for 5 food products in a different Swedish city.

2.3. Page LCA application on food waste in China

Ren Hui et al. (2006) mentioned that LCA has not been used in China on food before. They explored the method system using beer as examples, in which they analyzed the water/energy consumption per unit product and its environmental influencing factors, and got the conclusion that eutrophication, dust, solid waste are the major influence from beer life cycle. But they only include the major ingredients and energy consumption for beer, and also the waste generated from the processing, without considering the other ingredients, other parts affiliated to beer sales and consumption, let alone waste treatment process.

Ma Aijin et al. (2011) applied LCA in exploring food carbon emissions of the stages of raw material, production, consumption and disposition, and initially explored the general LCA framework and methods for the carbon emission calculation for food, and especially meat.

Wang Xiao et al. (2013) used LCA approach to analyze the carbon emission characteristics of food in China from 1996-2010, using brief statistics for energy/resource use in different parts of food supply chain, and concluded that diet structure, high amount of fertilizer application, as well as food waste are 3 main causes for increasing of GHGs from food industries.

There are other studies such as Hu Yue et al. (2013) which directly applied Gustafson data for food waste percentage in China, and calculated the rough resource and environmental influence, but he also pointed out how tremendously different China is when it comes fertilizer application amount and efficiency etc. And GAO Li-wei et al. (2015) summarized the global food waste studies, and concluded that studies on whole food supply chain are not enough. Cheng shengkui et al. (2017) explored the research on food waste, and brought forward the importance of LCA application on food waste, as well as a more complete life cycle inventory for food.

There are also thesis on household waste and kitchen waste management LCA analysis in different cities in China. Hao Xiaodi et al. (2017) compared 5 treatment methods (landfill, compost, anaerobic digestion (AD), smashing, and integrated treatment) for kitchen waste treatment, and concluded that AD, especially when kitchen waste can be mixed with other waste like sludge can be quite beneficial when it comes to energy generation and emission reduction.

It should be mentioned that other methods are applied to calculate the environmental influences from food and food waste other than LCA in some thesis. Such as Wang Lingen et al. (2012) etc.
Zhang Dan et al. (2016) using ecological footprint methods to calculate the environmental influences of catering industries food waste in Beijing.

3. Discussion
For food waste, LCA can identify the key food for environmental contribution, key parts within the whole chain that influence environment and energy consumption such as waste separation, transportation, treatment technologies, etc. It can also evaluate what improvement actions affect the environmental impact of the food chain. For specific step within the food cycle, using LCA is efficient in evaluating different scenarios as well.

From the literature reviewed, the LCAs have been applied in the environmental impacts analysis on single food, meals, on food waste from a region/globally, covering the whole process of food cycle or within a single step, food waste disposal approached are compared, many focusing on kitchken waste, but also some focusing on specific food, where new treatment methods like donation and re-manufacture into food products are analyzed in line with traditional way of food waste treatment like landfill, anaerobic digestion and incineration. Single food waste treatment and food waste mixed with different other materials for better recycling are analyzed as well. And further detailed studies on food waste footprint based on LCA are present. This paper shows a gradual development on the method application in this particular area. It can be seen that international-wise, LCA application on food waste are developing very fast and broad, and enters into a more detailed management stage (like the waste profile from different food production stages and its specific influences). The study on the early part of the food supply chain are limited, though. According to FAO, the food waste in developing countries especially occur in the early stage of the food cycle, thus it worth more efforts compared with developed countries.

The most studied categories for environmental impacts from food waste LCA are still focusing on GWP (Foster et al., 2006). Other impacts are not studied as widely as the carbon emissions. The LCA method itself has many shortcomings that requires further attention, which was mentioned by different scholars. S. Van Ewijk et al. (2016) mentioned the “inconsistent results” from LCA studies applied in solid waste studies which is a reflection of the the “uncertainties” association with such methodology. The main problem lies in finding the optimum improvement strategies and choosing the best alternative in a decision environment with multiple, and often conflicting, objectives. And it has been mentioned many times in different literature the “locality” of LCA method, meaning that influenced by different characteristics of local inputs, LCA must be applied in a local context with local data input to obtain a

Chinese food LCA studies have also started, but not so much literature on LCA studies about food waste are observed, except for kitchen/household waste management. There do have some papers and dissertations on the calculation of environmental influences from food waste using other methodologies, which shows people start to be aware of this question. And the big lack of LCA studies in food waste, especially on the first few stages of the food cycle, can probably be explained by the fact that there are no data available for food waste situation in China, as described by Liu Gang (2014), as data input is absolutely necessary for LCA analysis. There are many experiences or lessons that China can learn when adopting LCA method in food waste analysis, such as to study broad scope of environmental influences other than GWP, to focus more on the early stages of the food supply chain, etc.

4. Conclusion
This study shows that China food waste management can improve the LCA application in different aspects. And several focuses identified: 1) More application of LCA on food waste should be made on the early stage of the food cycle rather than just the kitchen waste; 2) Besides global warming potentials, other environmental influences should be studied more at the same time; 3) Food waste treatment can be studied broadly considering mixture with other substrates and using different methods; 4) Because of the local context are substantially different, (for instance, rice from southern
and northern parts of China requires different inputs/steps thus have different environmental profile), LCA based on a local context with local data/inventory are strongly needed; 5) further more detailed studies to support an elevated food waste management, such as food waste profile can be developed.

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