Global biomethanation potential from food waste – a review

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Abstract: Globally, there is a great variation in food production and food waste generation. These make the application of biomethanation to gain interest in reduction of harmful effects of the waste generated in the environment as well as human health. Furthermore, it could play an important role to compensate the loss in food security by energy security. The statistics of the global food production and waste generation was collected from the literature, it was found that roughly one-third of the edible parts of food produced for human consumption gets lost or wasted globally, which is about 1.3 billion ton per year. The total per capita production of edible parts of food for human consumption is, in Europe and North-America, about 900 kg/yr and, in sub- Saharan Africa and South/Southeast Asia, 460 kg/yr. Per capita food wasted by consumers in Europe and North-America is 95-115 kg/yr, while in sub-Saharan Africa and South/Southeast Asia is 6-11 kg/yr.

The results show that the amount of food wasted has a potential of generating 3.2*109 to 12.8*109 m^3 of biogas i.e. 1.92 *109 to 7.68*109 methane gas depends on the type of reactor.

It has been reported that if 5.5 million tons of food waste is treated by anaerobic digestion, it could generate enough electricity to power 164,000 houses. These make it possible for each and every country to generate methane from the available type of food waste.

Keywords: biomethanation, food waste, anaerobic digestion, per capita

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1 Introduction

11 September 2013, Rome - The waste of a staggering 1.3 billion t of food per year is not only causing major economic losses but also wreaking significant harm on the natural resources that humanity relies upon to feed itself, says a new FAO report.

Food Wastage Footprint: Impacts on Natural Resources, is the first study to analyze the impacts of global food wastage from an environmental perspective, looking specifically at its consequences for the climate, water and land use, and biodiversity.

Among its key findings: each year, food that is produced but not eaten guzzles up a volume of water equivalent to the annual flow of Russia's Volga River and is responsible for adding 3.3 billion t of greenhouse gases to the planet's atmosphere. And beyond its environmental impacts, the direct economic consequences to producers of food wastage (excluding fish and seafood) run to the tune of $750 billion annually, FAO's report estimates.

As global population increases as well as industrialization, energy demand around the world is increasing markedly. World energy consumption is expected to increase by 50% to 180,000 GWh/yr by 2020 (Fernando et al., 2006), due primarily to increases in demand from rapidly growing Asian countries such as China and India (Khanal, 2008). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), fossil fuel combustion already contributes 57% of emissions that cause global warming. Thus, to address future energy needs sustainably,

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renewable sources of energy must be developed as alternatives to fossil fuels.

To aid in developing such renewable energy alternatives, environmental scientists and engineers should consider anaerobic processes for waste treatment as alternatives to aerobic processes. When aerobic processes are used for waste treatment, the low energy compounds carbon dioxide and water is formed; much energy is lost to air – about 20 times as much as with an anaerobic process (Deublein and Steinhauser, 2008). Anaerobic processes produce products of high energy like methane. Methane can be captured and burned as an energy source, and used to power gas-burning appliances or internal combustion engines, or to generate electricity.

Therefore the **scope** of this paper is to review:

- The status of the global food production and food waste generation
- Classification of types of food waste from different sources.
- The anaerobic process of food waste.
- The global potential of biomethanation from food waste.

The scope was achieved through the following objectives:

1- To review the status of energy with the increase of global population and industrialization.

2- To state the amount of food waste generation and negative effects on both environment and human health.

3- To elaborate the benefits of anaerobic digestion of food waste in reducing the harmful effects of greenhouse gas and to reducing the emissions of fossil fuel combustion that cause climate change

2 Materials and methods

2.1 Definition of food waste

Food losses refer to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption. Food losses take place at production, postharvest and processing stages in the food supply chain (Parfitt*et al.*, 2010). Food losses occurring at the end of the food chain (retail and final consumption) are rather called “food waste”, which relates to retailers’ and consumers’ behaviour. (Parfitt*et al.*, 2010).

“Food” waste or loss is measured only for products that are directed to human consumption, excluding feed and parts of products which are not edible. Per definition, food losses or waste are the masses of food lost or wasted in the part of food chains leading to “edible products going to human consumption”.

Therefore food that was originally meant to human consumption but which fortuity gets out the human food chain is considered as food loss or waste even if it is then directed to a non-food use (feed, Bioenergy…). This approach distinguishes “planned” non-food uses to “unplanned” non-food uses, which are hereby accounted under losses.

2.2 Types of food losses/waste

Five system boundaries were distinguished in the food supply chains (FSC) of vegetable and animal commodities. Food loss/ waste were estimated for each of these segments of the FSC. The following aspects were considered:

Vegetable commodities and products:

- **Agricultural production:** losses due to mechanical damage and/or spillage during harvest operation (e.g. threshing or fruit picking), crops sorted out post-harvest, etc.
- **Postharvest handling and storage:** including losses due to spillage and degradation during handling, storage and transportation between farm and distribution.
- **Processing:** including losses due to spillage and degradation during industrial or domestic processing, e.g. juice production, canning and bread baking. Losses may occur when crops are sorted out if not suitable to process or during washing, peeling, slicing and boiling or during process interruptions and accidental spillage.

- **Distribution:** including losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.
- **Consumption:** including losses and waste during consumption at the household level.

Animal commodities and products:

- **Agricultural production:** for bovine, pork and poultry meat, losses refer to animal death during breeding. For fish, losses refer to discards during fishing. For milk, losses refer to decreased milk production due to dairy cow sickness (mastitis).
- **Postharvest handling and storage:** for bovine, pork and poultry meat, losses refer to death during transport to slaughter and condemnation at slaughterhouse. For fish, losses refer to spillage and degradation during icing, packaging, storage and transportation after landing. For milk, losses refer to spillage and degradation during transportation between farm and distribution.
- **Processing:** for bovine, pork and poultry meat, losses refer to trimming spillage during slaughtering and additional industrial processing, e.g. sausage production. For fish, losses refer to industrial processing such as canning or smoking. For milk, losses refer to spillage during industrial milk treatment (e.g. pasteurization) and milk processing to, e.g., cheese and yoghurt.
- **Distribution:** includes losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.
- **Consumption:** includes losses and waste at the household level.

2.3 Quantification of food losses and waste

Physical mass of food produced for human consumption and of food lost and wasted throughout the food supply chain have been quantified, using available data, results from the literature on global food waste and SIK's own assumptions. For each commodity group a mass flows model was used to account for food losses and waste in each step of the commodity's FSC.

The production volumes for all commodities (except for oil crops and pulses) were collected from the FAO Statistical Yearbook 2009 (FAOSTAT 2010a). The production volumes for oil crops and pulses were collected from FAO's Food Balance Sheets (FAOSTAT 2010d).

Allocation factors have been applied to determine the part of the produce oriented to human consumption (and not for animal feed). Conversion factors have been applied to determine the edible mass were as follow:

Conversion factor determines the part of the agricultural product that is edible.

Allocation factor determines the part of the agricultural produce that is allocated for human consumption.

LIC: low-income countries; MHIC: medium/high income countries; FBS: food balance sheets.

Cereals:

Conversion factors: wheat, rye = 0.78; maize, millet, sorghum =0.79 (LIC), =0.69 (MHIC); rice = 1; oats, barley, other cereals = 0.78. Source: Wirsenius (2000)

Allocation factors for losses during agricultural production and postharvest handling and storage: Europe = 0.35; NA&Oce = 0.50; Ind. Asia = 0.60; SSA = 0.75; NA, WA&CA = 0.60; S&SE Asia = 0.67;LA = 0.40.

Roots & Tubers:

Proportion of roots and tubers utilized fresh:

Assumed average proportion of cassava utilized fresh in SSA = 50%. Source: Westby (2002). In LA = 20%. Source: Brabet (1998).

Assumed average proportion of potato utilized fresh in Europe and NA&Oce = 27%. Source: USDA (2010b). In NA, WA&CA = 81%. Source: Potatoes South Africa (2010). In S&SE Asia = 90%. Source: Pendey (2009) and Keijbets (2008). In Ind. Asia = 85%. Source: Keijbets (2008) and FAOSTAT (2010a).

Conversion factors: Peeling by hand = 0.74; Industrial peeling = 0.90. Source: UNICEF (1990)

Oil crops & pulses:

Allocation factors: SSA = 0.63; NA, WA&CA = 0.12; S&SE Asia = 0.63; LA = 0.12; Europe = 0.20;NA&Oce = 0.17; Ind. Asia = 0.24. Source: FAOSTAT (2010d)

Fruit & Vegetables:

Proportion of fruit and vegetables utilized fresh:Assumed average proportion of fruit & vegetables utilized fresh in SSA = 99%. Source: Mungai (2000).

In NA, WA&CA = 50%. Source: Guajardo (2008). In S&SE Asia = 95%. Source: FAO (undated). In LA= 50%. Source: Guajardo (2008). In Europe and NA&Oce = 40%. Source: USDA (2010c). In Ind. Asia= 96%. Source: Cheng (2008)

Conversion factors: peeling by hand = 0.8; industrial peeling = 0.75; mean = 0.77. Source: own investigation and UNIDO (2004c)

Fish & Seafood:

Proportion of fish and seafood utilized fresh:

Assumed average proportion of fish & seafood utilized fresh in LIC = 60%; in MHIC = 4 %. Source: FAO (2009) Conversion factor: Average conversion factor for fish & seafood = 0.5. Source: FAO (1989).

At each stage of the Food Supply Chain, losses andwaste were estimated using FAO's Food Balance Sheets from the year 2007 and results from a thorough literature search on the topic of global food waste.

2.4 Conversation of waste to bioenergy

2.4.1Conversion of the food waste in to biogas (m^3)

Based on the fact that some digesters can yield 20 m^3 of biogas per tonne of waste while others can yield as much as 800 m^3/t (www.electrigaz.com/faq_en.htm). Therefore the amount of the food waste generated was converted into biogas m^3

2.4.2. Conversion of biogas into methane (m^3)

Biogas is typically composed of 60% methane and 40% CO_2 (www.electrigaz.com/faq_en.htm). The amount of the determined biogas was converted into methane.

3 Global food production status

Figure 1illustrates the 2007 production volumes of all commodity groups in their primary form, including animal feed products (which are then factored out using allocation factors), and in the regions of the world studied (Statistical Yearbook 2009 and FAO's FBS, 2007).

Meat production in Industrialized Asia was dominated by large pig (around 46 million t) and chicken (around 12 million t) production. Meat production in Europe was dominated by pig (around 27 million t) while it was more diversified in North America and Oceania, with chicken (18 million t), cattle (16 million t) and pig (12 million t).

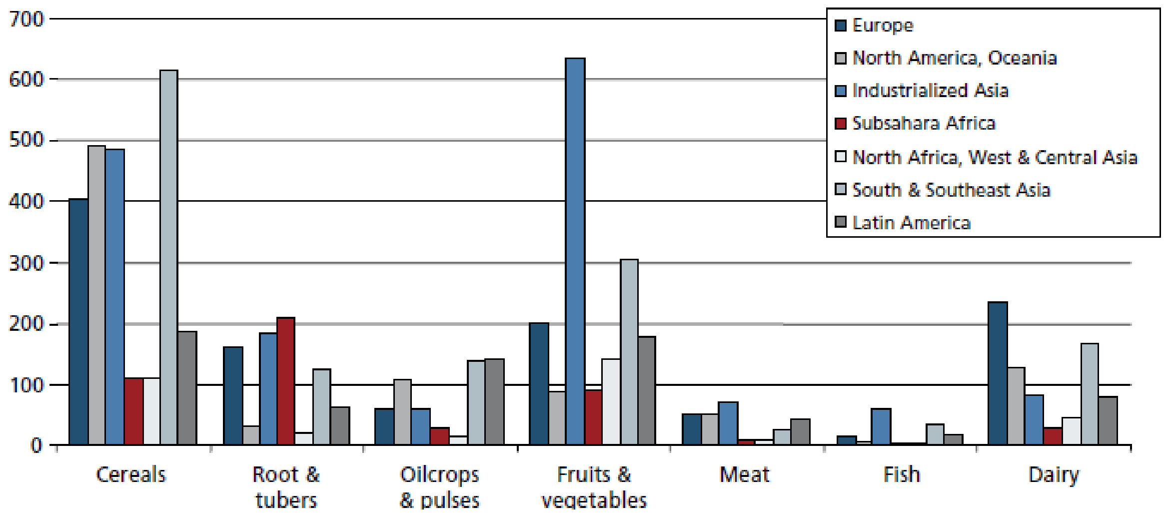

Figure1 Production volumes of each commodity group, per region (million t)

In developing regions, meat in Latin America was dominated by large cattle (around 15 million t) and chicken (around 17 million t) production. Meat produced in South and Southeast Asia mainly consisted of pig (7 million t) and chicken (9 million t). Animal production in sub-Saharan Africa mostly consisted of cattle (around 4 million t) and in North Africa, West and Central Asia it was mostly chicken (around 4 million t) production.

4 Extent of food losses and waste

Roughly one-third of the edible parts of food produced for human consumption gets lost or wasted globally, which is about 1.3 billion t per year. Food is wasted throughout the FSC, from initial agricultural production down to final household consumption. In medium- and high-income countries food is to a great extent wasted, meaning that it is thrown away even if it is still suitable for human consumption. Significant food loss and waste do, however, also occur early in the food supply chain. In low-income countries food is mainly lost during the early and middle stages of the food supply chain; much less food is wasted at the consumer level.

Figure 2shows that the per capita food loss in Europe and North-America is 280-300 kg/yr. In Sub-Saharan Africa and South/Southeast Asia it is 120-170 kg/yr. The total per capita production of edible parts of food for human consumption is, in Europe and North-America, about 900 kg/yr and, in sub- Saharan Africa and South/Southeast Asia, 460 kg/yr.

Per capita food wasted by consumers in Europe and North-America is 95-115 kg/yr, while this figure in sub-Saharan Africa and South/Southeast Asia is only 6-11 kg/yr.

Food losses in industrialized countries are as high as in developing countries, but in developing countries more than 40% of the food losses occur at post-harvest and processing levels, while in industrialized countries, more than 40% of the food losses occur at retail and consumer levels. Food waste at consumer level in industrialized countries (222 million t) is almost as high as the total net food production in sub-Saharan Africa (230 million t).

The graphs of the seven commodity groups below show the percentage food losses and waste of the edible parts of food products that were produced for human consumption.

In the case of cereals (Figure 3), wheat is the dominant crop supply in medium- and high-income countries, and the consumer phase is the stage with largest losses, between 40%-50% of total cereal food waste.

In low-income regions rice is the dominant crop, especially in the highly populated region of South and Southeast Asia. For these regions, agricultural production and postharvest handling and storage are stages in the FSC with relatively high food losses, as opposed to the

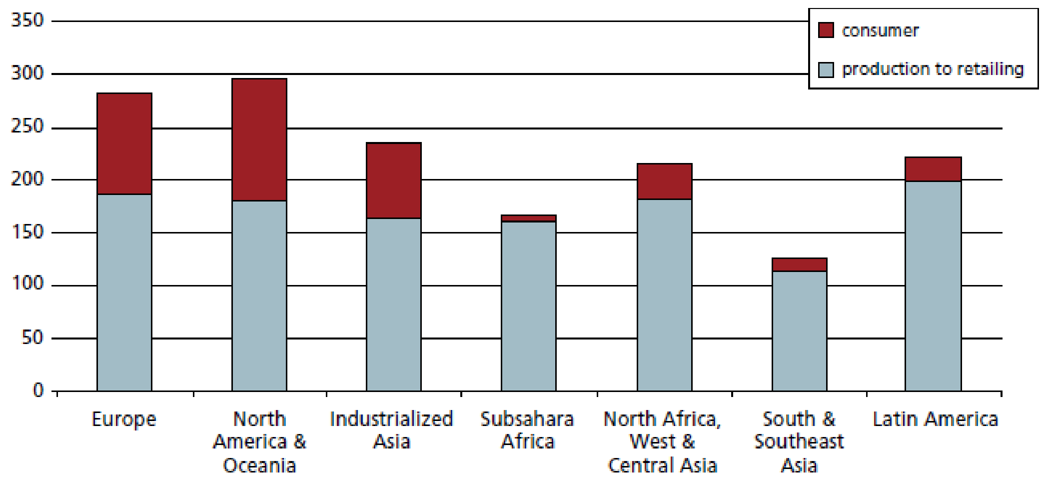

Figure 2 Per capita food losses and waste, at consumption and pre-consumptions stages, in different regions

distribution and consumption levels.

In the roots and tubers group (Figure 4), potato (sweet potato in China) is the dominating crop supply in medium and high income countries. Results indicate that all three medium and high income regions loose the largest volumes during agricultural production. This mainly depends on postharvest crop grading, due to quality standards set by retailers. Food waste at the consumer level is, however, also high.

Cassava is the dominant supply crop in SSA and LA and potato the dominant crop in North America, West Asia and Central Asia, and South and Southeast Asia. For these regions, agricultural production and postharvest handling and storage are stages in the FSC with relatively high food losses, as opposed to the distribution and consumption levels. One reason for this is that fresh roots and tubers are perishable, which make these products easily damaged during harvest and postharvest activities, especially in the warm and humid climates of many developing countries.

In the oil crops and pulses commodity group (Figure 5), sunflower seed and rape seed are the dominating crop supplies in Europe, while soybeans are the dominating crop supply in North America and Oceania and Industrialized Asia. Losses in all medium and high income regions are relatively large during agricultural production, contributing waste percentages between 6% and 12% during harvest.

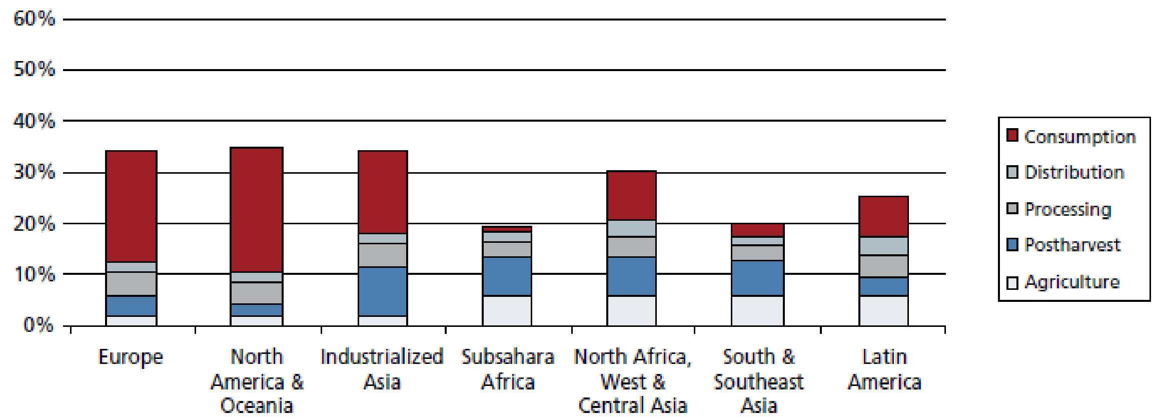

Figure 3 Part of the initial production lost or wasted, at different FSC stages, for cereals in different regions

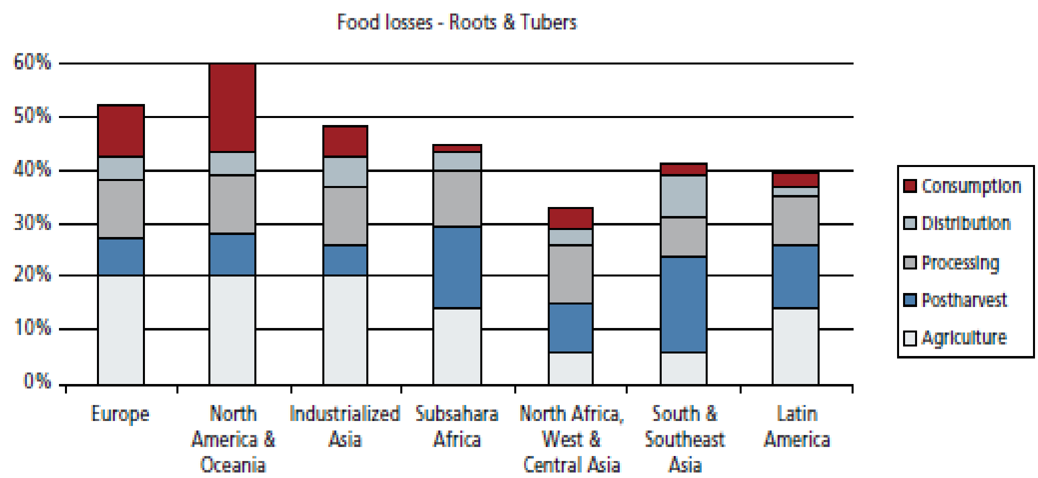

Figure 4 Part of the initial production lost or wasted at different stages of the FSC for root and tuber crops in different region

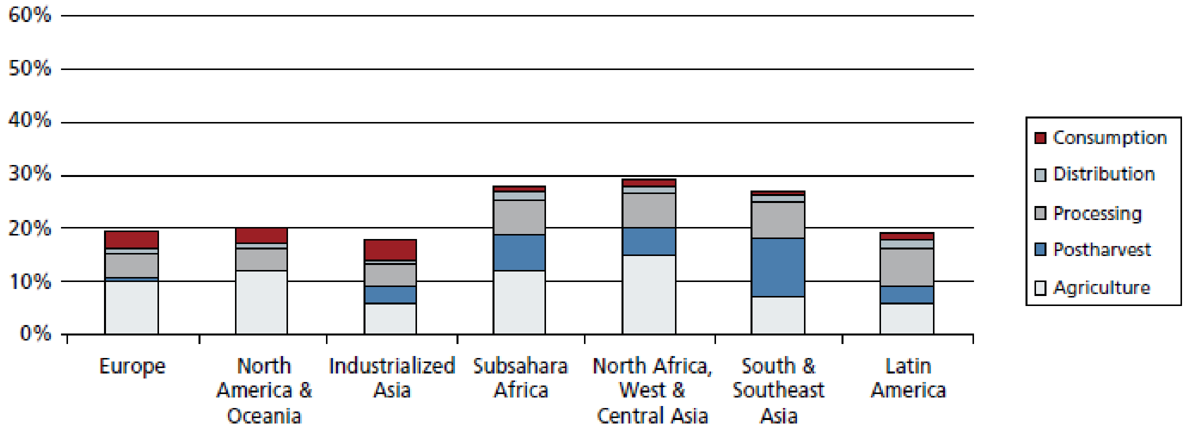

Figure 5 Part of the initial production lost or wasted at different stages in the FSC for oilseeds and pulses in different regions

Groundnut is a dominant oil crop in SSA; soybean and olives in North America, West and Central Asia; soybean and coconut in South and Southeast Asia and soybean in Latin America. Losses in these regions are largest in agricultural production and during postharvest handling and storage. This is, however, also due to the fact that oil crops in the distribution and consumption stages are mainly consumed as vegetable oils, products which are wasted relatively little compared to fresh products.

In the fruits and vegetables commodity group (Figure 6), losses in agricultural production dominate for all three industrialized regions, mostly due to postharvest fruit and vegetable grading caused by quality standards set by retailers. Waste at the end of the FSC is also substantial in all three regions, with 15-30% of purchases by mass discarded by consumers.

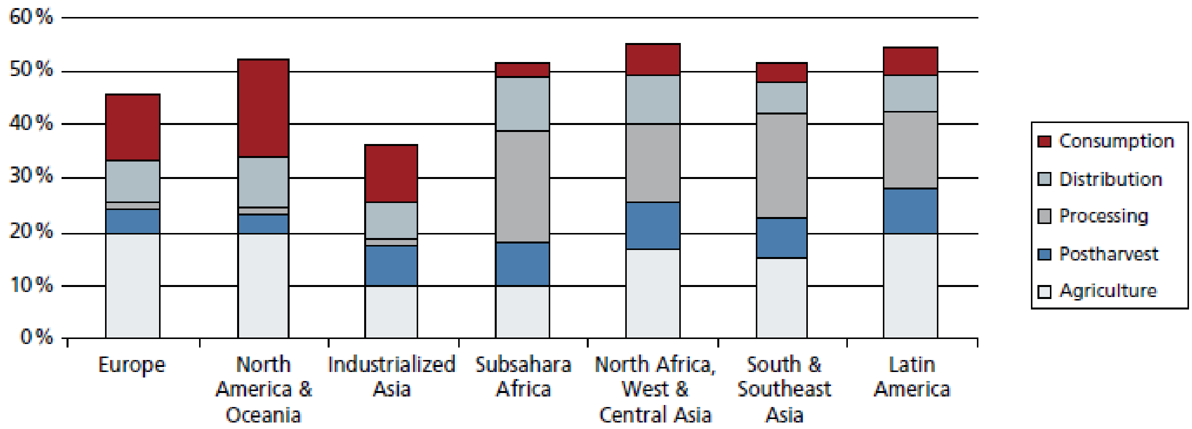

Figure 6 Part of the initial production lost or wasted at different stages of the FSC for fruits and vegetables in different regions

In developing regions losses in agricultural production dominate total losses throughout the FSC. Losses during postharvest and distribution stages are also severe, which can be explained by deterioration of perishable crops in the warm and humid climate of many developing countries as well as by seasonality that leads to unsalable gluts.

In the case of meat and meat products (Figure 7): losses and waste in industrialized regions are most severe at the end of the FSC, explained by a high per capita meat consumption combined with large waste proportions by retailers and consumers, especially in Europe and the U.S. Waste at the consumption level makes up approximately half of total meat losses and waste. The relatively low levels of waste during agricultural production and postharvest handling and storage can be explained by relatively low losses due to animal mortality during breeding and transportation to slaughter.

Losses in all developing regions are distributed quite equally throughout the FSC, but notable is the relatively high losses in agricultural production in SSA.This is explained by high animal mortality, caused by frequent diseases (e.g. pneumonia, digestive diseases and parasites) in livestock breeding (see Figure 8).

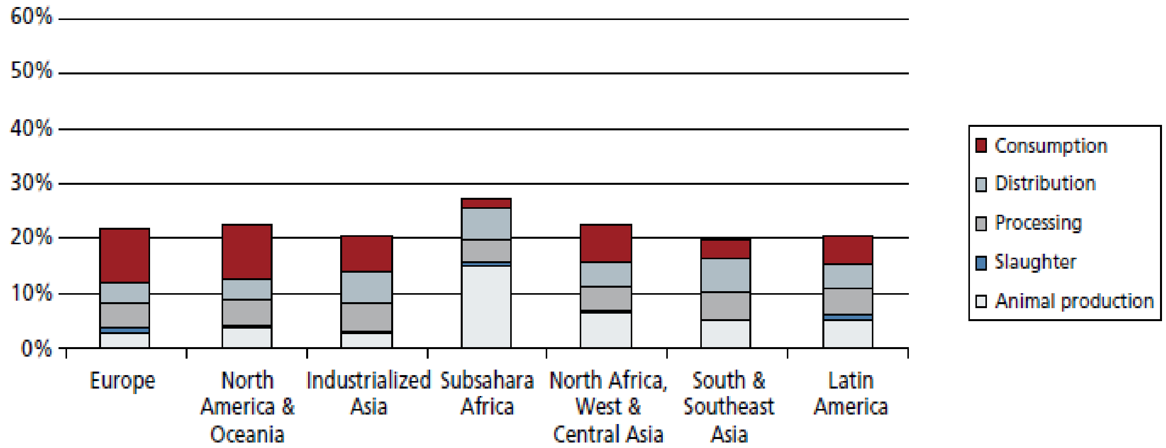

Figure 7 Part of the initial production lost or wasted for meat products at different stages in the FSC in different regions

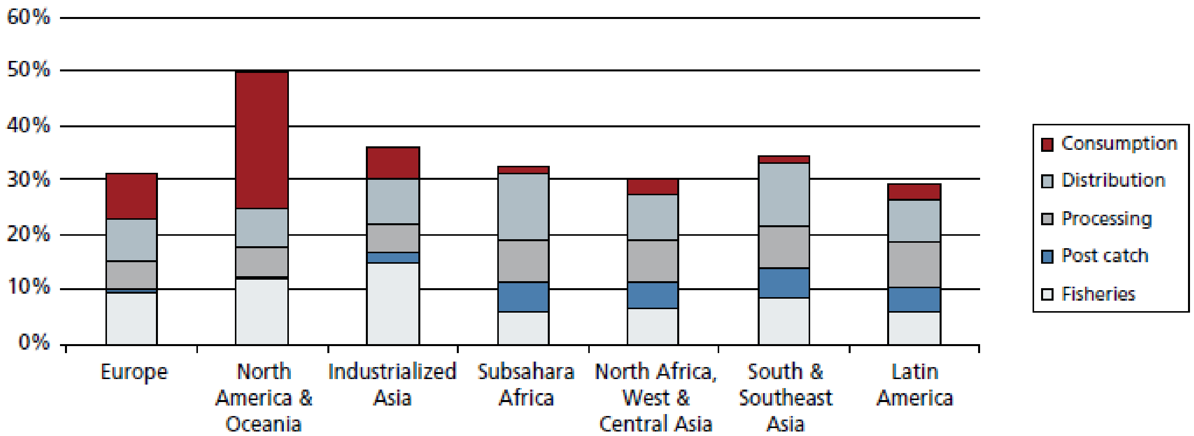

Figure 8 Part of the initial catching (fish and seafood harvested) discarded, lost and wasted in different regions and at different stages in the FSC

5 Food Waste potential for Biomethanation

Food waste represents a desirable waste stream that holds a significant potential as a resource for energy production through anaerobic digestion, since it is biodegradable with high moisture content. The amount of waste from household food leftovers in urban communities is increasing with the update of the source-sorted OFMSW management. Also, the growing demand for food products in developed countries has led to an increase in productivity from food processing industries. According to De Baere (2000),in Europe, in the early 1990 ́s anaerobic digestion of bio-waste mixed with grey wastes were similar, about 100 000 tons/year for each, while bio-waste treatment has been prevailing in recent years, reaching levels of 900 000 tons/year in 2001. This fact is due to the introduction of source and/or separate collection of the OFMSW in most of the urbanised areas of the European Union. However, there are very few reports of anaerobic digestion plants operating entirely on the source segregated food waste fraction (Climenhaga*et al.*, 2008). Unfortunately, digestion plants for this purpose are in operation only in few countries, and the capacity of the plants is still limited compared to the organic waste potential (Davidson *et al.,* 2007).

6 Benefits of Anaerobic Digestion

This process of bio-waste-management and of energy production has many environmental benefits and offers significant advantages over other forms of waste treatment, including:

- less biomass sludge is produced in comparison to aerobic treatment technologies (Ward el, al., 2008);
- well known advantages for the treatment of high organic concentration wastewaters (Sayed *el, al*., 1988; Mendez *et al.,* 1989; Rico *el, al.,* 1991; Hawkes *et al.*, 1995);
- Successful in treating wet wastes of less than 40% dry matter (Mata- -ALVarez, 2002);
- The possibility of nutrient recycling and reduction of waste volumes (Ghoshetal., 1975; Van Lier *et al.,* 2001). The slurry produced (digestate) is an improved fertiliser in terms of both its availability to plants (Tafdrup, 1995) and its rheology (Pain &Hepherd, 1985);
- Effective pathogen removal (Bendixen, 1994; Lund *etal*., 1996; Sahlstrom, 2003), this is especially true for multi-stage digesters (Kunte*et al.,* 2004; Sahlstrom, 2003);
- Minimal odour emissions (Smet*et al.,* 1999);
- High degree of compliance with many national waste strategies implemented to reduce the amount of biodegradable waste entering landfill (Ward *et al.,* 2008).

However, problems such as low CH4 yield and process instability are often encountered in anaerobic digestion, preventing this technique from being widely applied (Bolzonella*et al.,*, 2006).

There is a long tradition of treating sewage sludge an aerobically at wastewater treatment plants to reduce the volume of sludge, but the process has not been focused, until recently, on optimal biogas production. Considering the general problems related to one-source waste fermentation, co-digestion seems to be a promising solution (Cecchi*et al.*, 1996). This approach can be a very strong option to improve the CH4 generation of the biogas plants already constructed. Hence, studies are needed to investigate the effects of variations in the input to a digester, and how the waste composition influences the overall stability of the process (Murto*et al.,* 2004) (see Table 1).

Table 1Categorization of substrates for anaerobic digestion and the biogas yield attained in batch assays at mesophilic temperatures (adapted from BRAUN ET AL., 2003)

Substrate	Excellent	Good	Poor	Biogas yield $m^3/(kg.VS_{added})$ [days]
Biogenic material from agriculture:				
Straw and other plant residues			x	
Green plant material, crops grain and silages		x		
Harvest residues		x		
Animal Manure:				
Chicken manure		x		
Liquid Pig manure	x			
Cow manure		x		
Food industry waste:				
Expired food		x		
Fast food				0.7 [35]
Fast food leftovers				0.5-1.1 [33]
Confectionary		x		
Whey	x			
Waste from canning and frozen foods		x		
Waste from fruit juice production		x		
Animal fat from slaughterhouse	x			1.0 [33]
Wastes from plant and animal fat production:				
Spoil plant oils	x			
Oil seed residues		x		
Fat trap contents		x		
Fats		x		
Edible oil sludge	x			
Edible fat sludge	x			1.1 [30]
Wastes from source separated collection:				
Biogenic wastes		x		0.40 [27]
Garden-yard wastes			x	
Market wastes		x		0.90 [30]
Wastes from wastewater treatment				
Sludges	x			0.30 [30]
Oil and fat trap wastes		x		
Sludge from gelatine production	x			
Sludge from starch production	x			
Waste from rice starch production	x			

7 Digestion of Organic Waste

The basic principle of co-digestion consists in balancing several parameters in a selected substrate mixture. Such a balance involves qualitative and quantitative characteristics of waste originating from different sources. The quantitative character of individual component indirectly influences the quality of the mixture (Montusiewicz*et al.*, 2008).

Several researchers have studied the anaerobic co-digestion of sewage sludge with the organic fraction of municipal solid waste (OFMSW) or with agricultural wastes and stated that an enhancement in CH4 yield was achieved (Angelidaki & Ellehaard, 2003; Bolzonella*et al.*, 2006; Gomez *et al.*, 2006; Pavan*et al.*, 2007; Macias-Corral *et al.*, 2008; Romano & Zhang, 2008).

Therefore, anaerobic co-digestion of bio-waste and sludge can be considered a sustainable solution for small wastewater treatment plants in rural areas, where several different kinds of bio-waste are available to enhance biogas production (Pavan*et al.*, 2007). Apart from higher biogas yields due to positive synergetic effects on microorganisms (Cecchi*et al.*, 1996; Mata Alvarez *et al.*, 2000), there are other benefits of co-digestion approach, which are:

- Dilution of toxic substances coming from any of the substrates involved (Cecchi*et al.*, 1996; Murto*et al.*, 2004), including, possible removal of some xenobiotics (detoxification based on co-metabolism process) (Cecchi*et al.*, 1996);
- Improved nutrient balance (Cecchi*et al.*, 1996, Murto*et al.*, 2004);
- Reducing micro and macronutrient deficiency (Montusiewicz*et al.*, 2008);
- improving process stability (Montusiewicz*et al.*, 2008);
- The use of a co-substrate can also help to establish the required moisture contents of the digester feed (Sosnowski*et al.*, 2003). Better handling and digestibility can be achieved by mixing solid waste with diluted waste (Murto*et al.*, 2004);
- In addition, economic advantages can be significant, derived from the fact of sharing equipment (Mata-ALVarez*et al.*, 2000).

There are many examples of success from mixing organic wastes in anaerobic digestion. Co digestion of cattle manure slurry with fruit, vegetable wastes and chicken manures is a good example of success. Callaghan *et al*, (2002) blended high carbon-to-nitrogen (C/N) ratio and low C/N feedstock and improved digester performance. Also, co-digestion of sisal pulp and fish wastes had shown a 59%–94% increase in the CH_4 production yield as compared to sisal pulp and fish wastes digestion alone (Mshandete*et al.*, 2004). Additionally, Bolzonella*et al*, (2006) presented the results of two full-scale applications of the anaerobic co-digestion process of waste activated sludge together with the OFMSW. The experiences were carried out at Viareggio and Treviso wastewater treatment plants, in Italy. In the first plant, 3 t/d of source sorted OFMSW were co-digested with waste activated sludge, increasing 50% the biogas production. At the Treviso plant, 10 tons/day of separately collected OFMSW were treated using a low-energy consumption sorting line, in which 99% and 90% of metals and plastics respectively were removed. In these conditions, the biogas yield increased from 3 500 up to 17 500 m3/month.

Industrial costs were evaluated less than 50 €/t of organic waste, while the payback time was calculated as two years.

However, some drawbacks also exist, mainly due transport costs and the problems arising from the harmonisation of different policies of the waste generators (Mata-ALVarez*et al.*, 2000).

Optimization of CH_4 generation from anaerobic systems has been focusing on digester design and operation, although it has been stated that the feedstock is as important as the digester technology, if not more (Lissens*et al.*, 2001).

A brief survey of the most recent literature on the co-substrates used in the experimental work reported herein, with special emphasis for food waste, fat substrates and cow manure is presented shortly.

8 Classification of the Anaerobic Digestion (AD)Systems

There are many different technologies on the market that are used for AD treatment of the organic fraction of the MSW. These systems differ based on the design of the reactor and the operating parameters.

The design of the reactor depends on the feedstock that is going to be processed and varies from very simple and easy to maintain AD digesters used in rural China and India to very complex and automatic systems used lately in the developed world for treatment of the organic fraction of the solid waste (OFMSW). The feedstock also determines the need and type of pre-treatment. In the case of OFMSW the pre-treatment is usually big part of the AD plant and is necessary in order to clean up the feedstock to the required level as well as to separate as much as possible recyclable materials.

The design of the digester also depends on the amount of the available feedstock that determines the capacity of the reactor. The bigger systems have been proven to be reliable and economic, so the trend is to build bigger plants as will be shown later in this study (Ostrem&Themelis 2004).

Characterization of the AD systems based on the operating parameters is done by the following criteria:

a. Loading rate in total solids content:

- Low-solids content (<15%Total Solids) sometimes also called "wet digestion";

- High-solids content (25-30 % TS) also known as "dry digestion".

When the feedstock used is the organic fraction of the MSW both systems apply and have been proven successful. In both cases water needs to be added in order to lower the content of total solids. The "dry digestion" requires smaller and therefore less costly digesters on one side but more costly additional equipment for mixing and material flow on the other side (Ostrem&Themelis 2004)".

b. Operating temperature:

- Thermophilic AD processes operate in the temperature range of 50 ℃-65 ℃;

- Mesophilic AD processes operate at about 37 ℃.

Anaerobic digestion of the OFMSW is possible in both temperature ranges.

Thermophilic AD digesters have been shown to be more efficient in biogas production, faster rate of decomposition but with higher maintenance costs.

c. Number of reactors used in series:

- Single stage digester: All reactions take place in one reactor and environmental conditions are maintained at levels that suit all types of bacteria. Therefore, operating conditions for a particular stage are not optimal.

- Multi-stage digesters have physically separated biochemical reactions of hydrolysis and acidogenesis in different reactor vessels. Each vessel maintains the optimal environmental conditions for the microorganisms that facilitate the specific reaction that is happening inside. Therefore these systems can be more efficient.

Both types of AD systems are used in processing the OFMSW and further in this study specific cases will be described.

d. Method of introducing the feed into the reactor:

- Continuous flow reactors have feed and discharge flows in continuous or semi continuous manner. This is the most common form of industrial scale reactors.

- Batch reactors are loaded and allowed to react for a certain period (usually two weeks).

Digestion of the OFMSW is possible in both types of systems although there are advantages and disadvantages in both cases. For example the batch reactors need to be bigger in volume due to the long retention time while in the case of the continuous flow reactor the effluent is a mixture of partly and completely digested material (Ostrem&Themelis 2004).

9 Conclusion

For better identification of food production and estimation of food waste, the world has been divided into seven regions namely Europe, North America & Oceania (Australia, Canada, New Zealand, USA), Industrialized Asia (China, Japan, Republic of Korea), Sub-Saharan Africa (Eastern Africa, Middle Africa, Southern Africa, Western Africa), North Africa, Western Asia & Central Asia (Central Asia, Mongolia, Northern Africa, Western Asia), South and Southeast Asia (Asia South eastern Asia, Southern Asia) and Latin America (Caribbean, Central America, South America).

Eight major food commodities has been grouped as Cereals (Cereals Wheat, Rye, Oats, Barley, Other cereals, Maize, Rice, Millet, Sorghum), Starchy roots (Starchy roots), Oilcrops & Pulses (Oil crops, Pulses), Fruits (Fruits Apples, Bananas, Citrus, Grapes, Other fruits), Meat (Bovine meat, Mutton & Goat meat, Pig meat, Poultry meat), Fish & Seafood, Milk & Eggs, and Vegetables.

The global volume of food wastage is estimated to be 1.6 Gtonnes of “primary product equivalents”, while the total wastage for the edible part of food is 1.3 Gtonnes. This amount can be weighed against total agricultural production (for food and non-food uses), which is about 6 Gtonnes.

Global environmental hotspots related to food wastage at regional and sub-sectorial levels, for consideration by decision-makers wishing to engage into waste reduction:

- Wastage of cereals in Asia emerges as a significant problem for the environment, with major impacts on carbon, blue water and arable land. Rice represents a significant share of these impacts, given the high carbon-intensity of rice production methods (e.g. paddies are major emitters of methane), combined with high quantities of rice wastage.
- Wastage of meat, even though wastage volumes in all regions are comparatively low, generates a substantial impact on the environment in terms of land occupation and carbon footprint, especially in high income regions (that waste about 67 percent of meat) and Latin America.
- Fruit wastage emerges as a blue water hotspot in Asia, Latin America, and Europe because of food wastage volumes.
- Vegetables wastage in industrialised Asia, Europe, and South and South East Asia constitutes a high carbon footprint, mainly due to large wastage volumes.

The results of the study suggest that roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion t per year. This inevitably also means that huge amounts of the resources used in food production are used in vain, and that the greenhouse gas emissions caused by production of food that gets lost or wasted are also emissions in vain. Food is lost or wasted throughout the supply chain, from initial agricultural production down to final household consumption. In medium and high income countries food is to a significant extent wasted at the consumption stage, meaning that it is discarded even if it is still suitable for human consumption.

Significant losses also occur early in the food supply chains in the industrialized regions. In low-income countries food is lost mostly during the early and middle stages of the food supply chain; much less food is wasted at the consumer level.

Overall, on a per-capita basis, much more food is wasted in the industrialized world than in developing countries. We estimate that the per capita food waste by consumers in Europe and North-America is95-115 kg/yr, while this figure in Sub-Saharan Africa and South/Southeast Asia is only 6-11 kg/yr.

The causes of food losses and waste in low-income countries are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems. Given that many smallholder farmers in developing countries live on the margins of food insecurity, a reduction in food losses could have an immediate and significant impact on their livelihoods.

The global volume of food wastage is estimated to be 1.6 Gtonnes of “primary product equivalents”, while the total wastage for the edible part of food is 1.3 Gtonnes. This amount can be weighed against total agricultural production (for food and non-food uses), which is about 6 Gtonnes.

Without accounting for GHG emissions from land use change, the carbon footprint of food produced and not eaten is estimated to 3.3 Gtonnes of CO_2 equivalent: as such, food wastage ranks as the third top emitter after USA and China. Globally, the blue water footprint (i.e. the consumption of surface and groundwater resources) of food wastage is about 250 km3, which is equivalent to the annual water discharge of the Volga River, or three times the volume of Lake Geneva. Finally, produced but uneaten food vainly occupies almost 1.4 billion ha of land; this represents close to 30 percent of the world's agricultural land area. While it is difficult to estimate impacts on biodiversity at a global level, food wastage unduly compounds the negative externalities that mono cropping and agriculture expansion into wild areas create on biodiversity loss, including mammals, birds, fish and amphibians.

Finally the results show that the amount of food wasted has a potential of generating $3.2*10^9$ to $12.8*10^9$ m^3 of biogas i.e. $1.92 *10^9$ to $7.68*10^9$ methane gas depends on the type of reactor.

10 Recommendations

The statistics presented in the literature shows about 30% of the global food produced is wasted by different sources, this represent one of the major threat to the environment and human health in terms of greenhouse gases. Anaerobic digestion can be one of the key solutions for the abundant amount of the food waste. As shown in literature there is a great variation among the regions and type of food waste; this is a great indicator to utilize the waste for biomethanation using different approach of reactors design.

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