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Food waste generation and industrial uses: A review

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ABSTRACT

Food waste is made up of materials intended for human consumption that are subsequently discharged, lost, degraded or contaminated. The problem of food waste is currently on an increase, involving all sectors of waste management from collection to disposal; the identifying of sustainable solutions extends to all contributors to the food supply chains, agricultural and industrial sectors, as well as retailers and final consumers. A series of solutions may be implemented in the appropriate management of food waste, and prioritised in a similar way to waste management hierarchy. The most sought-after solutions are represented by avoidance and donation of edible fractions to social services. Food waste is also employed in industrial processes for the production of biofuels or biopolymers. Further steps foresee the recovery of nutrients and fixation of carbon by composting. Final and less desirable options are incineration and landfilling. A considerable amount of research has been carried out on food waste with a view to the recovery of energy or related products. The present review aims to provide an overview of current debate on food waste definitions, generation and reduction strategies, and conversion technologies emerging from the biorefinery concept.

1. Introduction

Food loss and food waste are often used in scientific literature to identify materials intended for human consumption that are subsequently discharged, lost, degraded or contaminated. The Food and Agriculture Organisation of the United Nations (FAO) defined food loss (FL) as any change in the availability, edibility, wholesomeness or quality of edible material that prevents it from being consumed by people. This definition was provided for the post-harvest period of food ending when it comes into the possession of the final consumer (FAO, 1981). Gustavsson et al. (2011) reported a similar definition of FL but included also the production stage of a food supply chain (FSC) and not only postharvest and processing stages. Parfitt et al. (2010) defined food waste (FW) as the food loss occurring at the retail and final consumption stages and its generation is related to retailers' and consumers' behaviour. Recently the European Project FUSIONS (Östergren et al., 2014) defined FW by using the resource flows of the agri-food system. FW was defined 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).*" Any food being produced for human consumption, but which leaves the food supply chain, is considered FW while organic materials produced for the non-food production chain are not considered FW (Östergren et al., 2014). The definitions of FL and FW therefore overlap. These terms are used in literature for material discharged at both the manufacturing and retail stages and the consumption or household levels, highlighting the need for commonly-agreed and improved definitions (Williams et al., 2015).

Discharge of food material occurs along the entire Food Supply Chain (FSC) and it involves all sectors of waste management from collection to disposal. Detailed analysis of a FSC system will highlight how the generation of waste material (food losses, organic waste or food waste) affects all sectors involved in the production, distribution and consumption of food (Parfitt et al., 2010; Pfaltzgraff et al., 2013). A FSC starts with the production of food from the agricultural sector where both farming and husbandry produce waste or sub-products that may be either organic waste (i.e. cornstalk, manure), food waste or food loss (i.e. low quality fruits or vegetable, damaged productions left in the field, good products or co-products with a low or absent commercial value). The food processing and manufacturing industry produces food losses and food waste throughout the entire production phase due to reasons such as: damage during transport or non-appropriate transport systems, problems during storage, losses during processing or contamination, inappropriate packaging. The retail system and markets also generate FL and FW, largely

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due to problems in conservation or handling, and lack of cooling/cold storage (Parfitt et al., 2010).

The generation of FW by the end consumer is caused by over- or non-appropriate purchasing, bad storage conditions, over-preparation, portioning and cooking as well as confusion between the terms "best before" or "use by" dates (Papargyropoulou et al., 2014). The generation of FW at household level is influenced by a series of interconnected factors, mainly socio-demographic characters of the household, consumption behaviour and food patterns (Glanz and Schneider, 2009).

FL and FW generation produces an impact at an environmental, social and economical level. From an environmental point of view, FL and FW contributes to Green House Gas (GHG) emissions during final disposal in landfills (uncontrolled methane release) and during activities associated with food production, processing, manufacturing, transportation, storage and distribution. Other environmental impacts associated with FL and FW are natural resource depletion in terms of soil, nutrients, water and energy, disruption of biogenic cycles due to intensive agricultural activities and all other characteristic impacts at any step of the FSC. Social impacts of FL and FW may be ascribed to ethical and moral dimension within the general concept of global food security. Economical impacts are due to the costs related to food wastage and their effects on farmers and consumer incomes (Lipinski et al., 2013; Papargyropoulou et al., 2014).

Similar to the Waste Management Hierarchy introduced in Europe, based on a hierarchy of solutions of distinct steps (waste prevention, reuse, recovery and recycling of materials, energy recovery and safe landfilling of residues) and often graphically represented by a reverse triangle (Cossu, 2009), the Environmental Protection Agency (EPA, 2014) defined the following hierarchy concept in relation to FW management: source reduction, feed hungry people, feed animals, industrial uses, composting, incineration or landfilling.

The first steps to be taken in reducing FW generation should commence by tackling the undesirable food surplus, and preventing over-production and over-supply of food (Papargyropoulou et al., 2014; Smil, 2004). The subsequent steps in the hierarchy foresee the utilisation of FW as animal feed or in the industrial sector. Several options are available for an industrial-scale use, ranging from the use of food waste for energy production by means of anaerobic digestion (e.g. bio-hydrogen or bio-methane productions) to the production of specific chemical compounds as precursors for plastic material production, chemical or pharmaceutical applications. Composting can be applied to recover nutrients or as a carbon sequestration process, through the formation of humic substances. Composting can be used to treat FW or residues from industrial processes (e.g. digestate). Landfilling or incineration represents the last and least desirable option. It is an acknowledged fact that biodegradable organic material is the main source of adverse environmental impacts and risks in traditional landfilling (odours, fires, VOC's, groundwater contamination by leachate, global climate changes, etc.) (*see also* Manfredi et al., 2010; Thomsen et al., 2012; Beylot et al., 2013) while thermal treatment, although providing for energy recovery, is limited by the low heating values of organic waste (Nelles et al., 2010). Accordingly, these options are not highly sought after (Papargyropoulou et al., 2014; Vandermeersch et al., 2014).

This paper reviews the data available on the magnitude of food waste generation, the strategies for food waste reduction and the possibilities reported and discussed in scientific literature for industrial uses of food waste.

2. Generation of food waste

The Food and Agriculture Organisation of the United Nations estimated that 32% of all food produced in the world was lost or wasted in 2009 (Gustavsson et al., 2011; Buzby and Hyman, 2012). While 870 million people are reported as being chronically undernourished, approximately 1.3 billion tons/year, i.e. one third of the food produced for human consumption, is wasted globally (Kojima and Ishikawa, 2013). In United States nearly 61 million tons of food waste are generated every year (GMA, 2012). Dee (2013) reported a food waste generation rate of 4 million tons per year in Australia. Other food waste generation data regards South Korea with 6.24 million tons per year (Hou, 2013), China with 92.4 million tons per year (Lin et al., 2011) and Japan where about 21 million tons of food waste were generated in 2010 (Kojima and Ishikawa, 2013). In Europe, food waste generation is estimated at 90 million tons annually (EC, 2013). Studies indicate the United Kingdom (UK) as the Country with the highest FW generation rate in Europe, reaching more than 14 million tons in 2013 (WRAP, 2013; Thi et al., 2015; Youngs et al., 1983). Quested et al. (2013) reported a generation of food waste at household level of 160 kg per year in UK, representing 12% of the food and drink entering a home and 30% of the general waste stream from UK household. Nellman et al. (2009) reported that a percentage ranging between 25% and 50% of food produced is wasted through the supply chain.

The order of magnitude of food waste generation is consistent and is not limited to developed Countries. Gustavsson et al. (2011) reported data on FW generation from different parts of the world, indicating that FW generation displays a similar order of magnitude in both industrialised Countries and developing Countries (DCs). Nevertheless, industrialised and developing Countries differ substantially. In the latter, more than 40% of food losses occur at the postharvest and processing stages, while in the former, about 40% of losses occur at the retail and consumer levels and, on a per-capita basis, much more food is wasted in the industrialised World than in DCs (Gustavsson et al., 2011).

The causes of food losses and waste in low-income Countries are mainly linked to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems. Many smallholder farmers in DCs live on the margins of food insecurity, and a reduction in food losses could have an immediate and significant impact on their livelihoods. Food supply chains in DCs should be strengthened, encouraging small farmers to organize, diversify and upscale their production and marketing. Investments in infrastructure, transportation, food industries and packaging industries should also be boosted, with both the public and private sectors playing an important role in achieving this.

The causes of food losses and waste in medium/high-income Countries relate mainly to consumer behaviour as well as to a lack of coordination between the various actors in the supply chain. Farmer-buyer sales agreements may contribute towards the wastage of farm crops. Food may also be wasted due to quality standards, with food items that do not fit with the required shape or appearance being rejected. On a consumer level, inadequate planning and expiry of "best before dates" likewise lead to large amounts of waste, combined with the at-times careless attitude of consumers. Food waste in industrialised Countries can be reduced by raising awareness amongst the food industries, retailers and consumers. This inevitably implies the unnecessary use of huge amounts of resources used in food production, and consequent increase in GHG emissions (Gustavsson et al., 2011).

In terms of the wasted investments, Nahman and de Lange (2013) estimated costs of edible food waste throughout the value chain in South Africa at approximately € 7.3 billion per annum, equivalent to 2.1% of annual gross domestic product. In the Unites States € 85 billion worth of food was estimated to be thrown away every year (Parfitt et al., 2010), € 28 billion in China (Zhou, 2013), € 27.8 billion in Australia (Dee, 2013), € 40 billion in Europe and nearly € 17 billion in the UK (WRAP, 2015).

Two aspects are in connection with the FW generation problem: prevention upstream and source segregation downstream. The primary action to be implemented in a successful FW management strategy is prevention of generation. The unavoidable generated FW amount needs, then, to be properly source segregated.

Prevention can be achieved either attempting to reduce losses and, therefore, decreasing the demand for food production, or diverting food losses, exceeds, and still safe and edible FW to other end-consumers. FW prevention campaigns have been promoted by advisory and environmental groups, and by media focus. Several papers have analysed the behaviour of companies and the population in developed Countries at different levels (household, restaurant, retail) to assess the governing factors influencing wastage of food products (Glanz and Schneider, 2009; Schneider and Lebersorger, 2009; Silvennoinen et al., 2012; Quested et al., 2013; Katajajuuri et al., 2014; Garrone et al., 2014; Graham-Rowe et al., 2014; Mena et al., 2014).

The focus of measures implemented will vary from Country to Country as highlighted by the work of Gustavsson et al. (2011). In developed Countries, food waste prevention should focus on the consumer's behaviours at household level, while in developing Countries it should focus increasingly on the retail and distribution system. The issues of food security and utilisation of food surplus to satisfy the nutritional needs of the poor represent indirect measures of FW prevention.

BIO Intelligence Service carried out a survey about FW generation across EU27 (EC, 2010) which resulted in a technical report where three priority options are highlighted: data reporting requirements, date labelling coherence, and targeted awareness campaigns.

The retail system may result in the generation of FW throughout various stages of food distribution and purchase: damage during transport or non-appropriate transport systems, problems during intermediate storage, losses during processing or contamination, inappropriate packaging, problems in conservation or handling, lack of cooling/cold storage. The food supply chain is also affected by loss of products nearing their expiry date (Aiello et al., 2014).

Other potential influences discussed in the literature can be divided into production and distribution level, and consumer level. Prevention strategies related to the first point are: development of markets for 'sub-standard' products, development of contract farming linkages between processors and farmer, marketing cooperatives and improved market facilities (Gustavsson et al., 2011) together with studies targeted in finding the optimal turnover frequency and wholesale pack size (Eriksson et al., 2014). Wasted investments should provide an incentive to push the food industry to reduce food waste generation in order to gain benefits on both the financial and environmental fronts. More specifically, interventions should first and foremost be targeted at the processing and packaging stages of the fruit and vegetable value chain, which alone accounts for the 13% of the total, as well as the distribution stage of the fruit and vegetable value chain, and the agricultural production and distribution stages of the meat value chain (Nahman and de Lange, 2013).

Betz et al. (2015) reported several actions geared at FW prevention and reduction, and indicated award schemes including incentives for food industries reducing FW generation. Future preventive measures should focus on the return of fresh products (shifting responsibilities from local shops to retail companies), internal optimisation (benchmarking amongst retail outlets within a company and application of best practices), training, information and education of employees, and amending the display at the end of the day when stocks are decreasing (Lebersorger and Schneider, 2014; Scherhaufer and Schneider, 2011). If food losses have to be discarded at the retailer's expense, this will act as an incentive for the outlet to minimise losses by optimising planning and ordering according to demand. Lebersorger and Schneider (2014) reported how, in the bread & pastry market, shifting the responsibility for unsold products from bakeries to the retail company would provide an incentive for retail outlets to reduce high quantities of wasted bread, for example by optimising demand planning and ordering and providing specific information to the supermarket customers.

On a household level, consumer behaviour may produce a huge impact on FW generation. Since the past Century, a wide range of factors influencing FW generation has been identified (Youngs et al., 1983) such as poor selection of food items, overbuying, poor food storage, excessive preparation losses, inability to use by-products, poor cooking/holding techniques, shortage of labour and equipment, excessive portion sizes, inability of the eater to remove all edible material, service method. Nowadays, over- or inappropriate purchasing, bad storage conditions, over-preparation, portioning and cooking as well as confusion between the terms "best before" or "use by" dates are still some of the main factors affecting food loss. This behaviour is influenced by a series of interconnected factors, mainly socio-demographic characteristics of the household, consumption behaviour and food patterns. Moreover, the barriers to surpass in achieving food loss minimisation at household level may also involve emotional or psychological aspects. The householder may wish to be a "good provider" in terms of supplying an abundance of healthy food for the family. A lack of food may produce a sense of inability to take care of the needs of the family, in this way driving the purchase of additional goods unnecessarily. Another example is avoidance of frequent trips to shops, resulting in the purchase of more food products to avoid running out. A general lack of awareness of the amount of FW generated at household level may exert a strong impact on food waste generation, due to the fact that small quantities thrown away a bit at a time with other waste does not provide the proper order of magnitude of the problem to consumers (Graham-Rowe et al., 2014). At consumer level a wide range of optimal behaviours can be listed: planning meals in advance, checking levels of food in cupboards and fridge prior to shopping, making a shopping list, storing meat and cheese in appropriate packaging or wrapping, storing vegetables and fruit in the fridge, using the freezer to extend the shelf-life of food, portioning rice and pasta, using up leftovers, using date-labels on food (Quested et al., 2013; Eriksson et al., 2014).

Additional measures should be considered, including the raising of customer awareness and information (Scherhaufer and Schneider, 2011). Whitehair et al. (2013), for example, found out how to simply reach a 15% reduction in FW generation from Universities' canteens by using written messages such as *'Eat what you take. Don't waste food'* or *'All taste, no waste'*.

With regard to the set of activities aimed at addressing lost, exceeding and safe wasted food to alternative end-consumers, donation of food constitutes a specific application of urban mining in view of the fact that food is recovered for its original purpose – human intake (Schneider, 2013a) and it is a valid alternative to minimise FW generation. Donation is a well-established food waste prevention measure implemented worldwide. The largest domestic hunger-relief organisation in the United States of America is Feeding America, a national network of more than 200 food banks operating within all 50 states, as well as the District of Columbia and Puerto Rico. It coordinates the distribution of edible food and grocery products with the help of 61,000 agencies, which supply 37 million people in the US. Three billion pounds of food were collected and distributed to people in need in 2009 (Echevarria et al., 2011).

The European Federation of Food Banks was established in 1984 and more than 30 years later there are 247 food banks operating in

21 European Countries. According to the reports published on their website, a total of 401,000 tons of food were collected and distributed to 31,000 social welfare organisations in 2011. It is estimated that these products are worth several hundred million € and approximately 5.2 million people are supported by these goods (FEBA, n.a.).

The largest contribution to the amount donated, with a share of 36% in 2006, was made by dairy products; the next largest product group was biscuits, cereals and starchy food with a share of 31%, and the third largest group was fruits and vegetables at 15% (European Food Banks, 2007; Schneider, 2013a). The majority of the products (55%) distributed by the European Food Banks are donated by the European Union or by member states (4%). Part of these products has been subject to a withdrawal or intervention approach used to stabilise market prices.

A central piece of legislation related to food donation is the General Food Law EC/178/2002. The aim of this Regulation is to provide a framework to ensure a coherent approach in the development of food legislation. It lays down definitions, principles and obligations covering all stages of food/feed production and distribution. According to Article 3.8, food donation falls under "placing on the market" operations, which are holdings of food or feed for the purpose of sale, including offering for sale or any other form of transfer, whether free of charge or not, and the sale, distribution, and other forms of transfer (EESC, 2014). This definition essentially points out that all food donations have to comply with the EU General Food Law. In other words, a food business operator has to comply with the same rules whether he is selling or donating food. Food banks and charities are considered "*food business operators" (EESC, 2014). According to Article 17 "food and feed business operators at all stages of production, processing and distribution within the businesses under their control shall ensure that foods or feeds satisfy the requirements of food law which are relevant to their activities and shall verify that such requirements are met*" (EESC, 2014). The food business operator is held responsible for any hygiene problem occurring only in the part of the food chain under its own control.

Donations to social services are beneficial from a series of different points of view. They reduce waste quantities and waste management costs (Alexander and Smaje, 2008; Schneider, 2013b) and may contribute towards promoting a positive image for the company together, and producing social benefits for the clients of these services. An example of how this can be implemented is represented by SOMA, a social supermarket set up in Linz, Upper Austria. This is a private initiative set up by food wholesalers with the intention of helping people in need by selling them low priced food products (Schneider, 2013a).

Aiello et al. (2014) developed a model to determine the optimal time to withdraw the products from the shelves, and to ascertain the quantities to donate to non-profit organisations and those to be sent to the livestock market maximising retailer profit. The optimal time is based on the assumption that the residual market demand will not be satisfied. Products near to their expiry date or damaged by improper transportation or production defects are usually scarcely appealing for the consumer in the target market, although maintaining their nutritional properties. In particular, after the optimisation of the variable 'time to withdraw the product from the shelves' the results show that 44.13% of food losses is suitable for donation to non-profit organisations, 28.69% to be sold at the livestock market, and 27.18% is disposed through the usual channel, namely the landfill.

When discussing the considerably large amounts of FW generated by consumers at a household level, it is necessary to point out the basic difficulty in achieving its optimal source segregation.

A series of factors that influence an active participation in source separation of food waste have been reported in literature, although the studies performed to date have reported varying results. Wan et al. (2013) conducted a questionnaire survey in Malaysia indicating education as the main factor affecting positive behaviour of consumers towards FW separation rather than convenience. The results of another study performed by Parizeau et al. (2015) indicated multiple relationships between FW segregation and household shopping practices, food preparation behaviours, household waste management practices and food-related attitudes, beliefs and lifestyles. The Authors observed that food and waste awareness, family and convenience lifestyles were related to FW generation, and concluded that convenience is a major issue when asking families to implement source segregation of FW at their house. Rousta et al. (2015) concluded that convenience and information go together. In fact, they concluded that information stickers about food waste sorting and property close location of drop-off point reduced the miss-sorted fraction by more than 70%.

Similarly, several studies showed that convenience in sorting, storage space at home, availability of sorting facilities, access to a curbside collection system and distance to collection points are important influential factors that can increase the recycling rate (Rousta et al., 2015; Ando and Gosselin, 2005; Barr and Gilg, 2005).

Bernstad (2014) highlighted how the need for a practical solution to improve FW separation was more important than providing appropriate information to consumers. Two different strategies aimed at increasing household source-separation of FW were evaluated in a Swedish residential area: the study involved the use of written information, distributed as leaflets amongst households, and installation of equipment for source-segregation of waste, aimed at increasing convenience FW sorting in kitchens. On the basis of the results obtained, distribution of written information amongst households failed to result in either an increased source-separation ratio, or a statistically significant and long-term increase of the amount of separately collected household FW. Conversely, following the installation of sorting equipment in all households in the area, both the source separation ratio and the amount of separately collected FW increased markedly. Changes remained consistent even months after the installation of the sorting equipment in the area (Bernstad, 2014).

Bernstad and la Cour Jansen (2011) compared composting, anaerobic digestion and incineration of FW within a life cycle approach, highlighting the crucial role of household participation for efficient source-separation of FW. Incorrect sorting reduces process efficiency and causes limitation in the final use of stabilised materials from biological treatments.

Prior to implementing any FW management strategy, probably the best would be to test the opinion of the population in the area of interest, in order to understand if attitude or convenience is the main predictor towards food waste separation. Thus, local Authorities will be guided to design the most meaningful intervention campaign.

3. Industrial uses

Increasing efforts are currently being focused on defining effective and stable means of obtaining biofuel and bio-products from FW. These options could afford benefits from an environmental point of view due to the reduction of methane gas emissions from landfills and the preservation of natural resources such as coal and fossil fuels, from a social point of view due to the lack of a food vs. fuel competition, and from an economical point of view thanks to costs saving linked to surplus food production and specific investments in establishing non-food crops dedicated to biofuel or bioplastic production.

Biorefineries are the concept underlying industrial FW utilisation. Similarly to the transformation by oil refineries of petroleum into fuels and ingredients for use in a wide variety of consumer products, biorefineries convert organic waste and biomasses (corn, sugar cane and other plant-based materials) into a range of ingredients for bio-based fuels or products. FW produced from agriculture and food processing is abundant and concentrated in specific locations. These materials could be less susceptible to deterioration if compared to FW produced at household level at the end of the FSC (Galanakis, 2012). These characteristics highlight the potential to develop industrial utilisation processes based on symbiosis where the wastes from one sector are inputs for other sectors. Availability of FW and location of potential users define the feasibility of industrial symbiosis (Mirabella et al., 2014). Therefore particular effort will be required from the agricultural and the industrial sectors to define sustainable and innovative processes for residues use and conversion, and from governments to stimulate and support this new vision with specific legislations. Industrial symbiosis within FSC and biorefineries represent possibilities for a complete utilisation of food processing residues, FL or FW in a vision of circular flow of resources, zero waste and final sink of stabilised residues (Cossu, 2012; Curran and Williams, 2012). The potential profitability of chemicals and biofuels produced from FW will stimulate investments on biorefinery chains rather than treatments of FW in traditional waste management processes. Finally legislations have to be developed to stimulate, support, define and control the marketability of chemicals, materials or biofuels obtained from agro-industrial residues or FW depending by their final applications (nutraceutical/pharma or non-feed/nonpharma applications) for a effective management of products traceability, health and safety issues and environmental protection (Lin et al., 2013; Tuck et al., 2012).

Valorisation routes of FW in biorefinery chains include both extraction of high-value components already present in the substrates to be used for nutrition or pharmaceutical applications and conversion into chemicals, materials or biofuels by the use of chemical or biological processes. Type, origin, seasonal generation and territorial distribution of FW will affect transport logistic for its utilisation and its compatibility with the transformation process. High and concentrated volumes of FW will be generally required to sustain large production capacities and meet economy of scale. Cost-effectiveness of conversion processes will then be ensured by security of supply at regional scale, low heterogeneity of substrates and large variety of extractable chemicals, biopolymers and biofuels. For these reasons, large fluxes of agro-industrial wastes seem to be more suitable for biorefinery chains where stability of supply and substrate homogeneity are required for extraction or production of specific commodities while source segregated organic waste from household or restaurants would be more indicated for treatment processes where composition variability, origins and contaminations do not represent limits for the selected process (Pfaltzgraff et al., 2013).

3.1. Biofuel and bioenergy production

Food waste is characterised by a variable chemical composition depending on its origin of production. FW may therefore comprise a mixture of carbohydrates, lipids and proteins, or, if generated from specific agro-industrial sectors, may be rich in one of these constituents. Different biofuels are therefore produced from FW using bioprocesses or thermo-chemical processes, depending on their chemical composition.

The use of FW for energy production was recently reviewed by Pham et al. (2015) and by Kiran et al. (2014). FW can be converted into biofuels or energy by means of the following processes:

- transesterification of oils and fats to produce biodiesel;
- fermentation of carbohydrates to produce bioethanol or biobutanol;
- anaerobic digestion to produce biogas (methane rich gas);
- dark fermentation to produce hydrogen;
- pyrolysis and gasification;
- hydrothermal carbonisation
- incineration;

Not all the listed processes are currently developed at industrial level for full-scale application. For example, FW is widely studied as a substrate for the biological production of hydrogen by dark fermentation, although no full-scale applications have been realised to date (Alibardi et al., 2014; De Gioannis et al., 2013). Incineration is a mature technology applied to reduce waste volumes and produce electrical energy and heat; however, the high moisture contents of FW limit its application together with the concerns of local communities on air emissions (Pham et al., 2015). Anaerobic digestion, on the contrary, is a technology facing growing interests and large applications (Clarke and Alibardi, 2010; Levis et al., 2010). The high biodegradability and moisture content of FW are ideal characteristics for biogas production and digestion residues can be used as soil conditioner or amendment (digestate) or as nutrient source (e.g. ammonia or struvite).

Biodiesel can be defined as fatty acid alkyl esters (methyl/ethyl esters) of short-chain alcohols and long-chain fatty acids derived from natural biological lipid sources such as vegetable oils or animal fats, which have had their viscosity reduced by means of a process known as transesterification, and are suited to use in conventional diesel engines and distributed through existing fuel infrastructure. Any fatty acid source may be used to prepare biodiesel (Refaat, 2012). Thus, any animal or plant lipid should represent a ready substrate for the production of biodiesel. However the use of edible vegetable oils and animal fats for biodiesel production has traditionally been of high concern due to their competing with food materials. The use of non-edible vegetable oils in biodiesel production is likewise questionable, as the production of crops for fuel implies an inappropriate use of land, water, and energy resources vital for the production of food for human consumption; the use of waste oil may therefore represent a more realistic and effective element for use in the production of biodiesel (Gasparatos et al., 2011; Timilsina and Shrestha, 2011; Pirozzi et al., 2012; Refaat, 2012).

The new process technologies developed in recent years have enabled the production of biodiesel from recycled frying oils, resulting in a final quality comparable to that obtained with virgin vegetable oil biodiesel. Canakci (2007) reported that the annual production of oils, greases and animal fats from restaurants in the United States could replace more than 5 million litres of diesel fuel if collected and converted to biodiesel. Waste cooking oil requires a series of pre-treatment steps to eliminate solid impurities and reduce free fatty acids and water contents. The pre-treatment process may include washing, centrifugation, flash evaporation, and acid esterification. Final ester yield could be up to 80% (Yaakob et al., 2013). These results are expected to encourage the public and private sectors to improve the collection and recycling of used cooking oil to produce biodiesel.

Waste oils can be co-treated with animal fats from slaughterhouses and fleshing oils from leather industries to gather cheap biodiesel feedstock (Alptekin et al., 2014). FW can also be used to grow microorganisms, microalgae or insects rich in lipids from which biodiesel can be produced (Ghanavati et al., 2015; Kiran et al., 2014; Li et al., 2011).

First-generation bioethanol can be derived from renewable sources of virgin feedstock; typically starch and sugar crops such as corn, wheat, or sugarcane. Indeed, most of the feedstocks used in first generation biofuel production are food crops. For this reason, biofuel expansion may compete with food production both directly (food crops diverted for biofuel production) and indirectly (competition for land and agricultural labour) (Gasparatos et al., 2011). These barriers can be partly overcome by the utilisation of lignocellulosic materials for the production of the so-called second-generation bioethanol. One potential advantage of cellulosic ethanol technologies is that they avoid direct competition for crops used in the food supply chain, as the materials used are not edible; this option however should be limited to cases in which an overt sustainable surplus of crops occurs or where crop wastes and wood wastes are available as feedstock. (Timilsina and Shrestha, 2011; Pirozzi et al., 2012; Refaat, 2012). Cellulosic ethanol has a number of potential benefits over corn grain ethanol, but although the cost of biomass is low, releasing fermentable sugars from these materials remains challenging.

Bioethanol can be produced from FW and agricultural waste, the latter being cost-effective, renewable and abundant substrates (Kiran et al., 2014; Sarkar et al., 2012). Pre-treatments are frequently applied to improve carbohydrate saccharification of organic substrates, as yeast cells cannot ferment starch or cellulose directly into bioethanol. Cekmecelioglu and Uncu (2013) demonstrated the feasibility of lowering ethanol production costs using kitchen wastes as substrate, and by excluding the fermentation nutrients traditionally used in fermentation practice. Pre-treatment prior to enzymatic hydrolysis was not required to obtain high glucose levels from the kitchen wastes, and the nutrients present provided sufficient nutritive medium for yeast to produce high ethanol yields (Cekmecelioglu and Uncu, 2013). Kim et al. (2011) reported ethanol yields from FW rich in carbohydrates between 0.3 and 0.4 g ethanol per g total solids. Waste fruits may also represent a substrate for bioethanol production. For example, banana waste or rotten banana, peels and sub-quality fruits have been extensively studied as substrates for bioethanol production (Graefe et al., 2011; Oberoi et al., 2011; Hossain et al., 2011; Arumugam and Manikandan, 2011; Gonçalves Filho et al., 2013; Bello et al., 2014).

Butanol is obtained from food waste by fermentation processes using *Clostridium acetobutylicum* bacteria. This organism features a number of unique properties, including the ability to use a variety of starchy substances and to produce much better yields of acetone and butanol than those obtained using Fernbach's original culture (Stoeberl et al., 2011). Butanol as fuel or blending component has several advantages compared to ethanol, for example a lower vapour pressure, improved combustion efficiency, higher energy density, and it can be dissolved with vegetable oils in any ratio reducing their viscosity. Results for butanol production indicated a potential of 0.3 g of butanol from 1 g carbohydrates from waste whey, a substrate characterised by high lactose content. Whey production worldwide, estimated in approximately $160 * 10^6$ Mg/year, contains about $8 * 10^6$ Mg of carbohydrates that could be converted into $2.4 * 10^6$ Mg solvents or fuels every year (Stoeberl et al., 2011). Similarly, industrial starchy food waste such as inedible dough, bread and batter liquid represent feasible alternative substrates for fermentative production of butanol with butanol yields of approximately 0.3 g butanol per g of FW (Ujor et al., 2014).

Studies indicate therefore the feasibility of alcohol production from specific fractions of FW and these technologies could also contribute to solve the debate on the use of food crops for energetic purposes. Anyway the overall economic viability still has to be evaluated and further studies are required to identify optimal conditions for cost minimisation and market development (Pham et al., 2015).

Anaerobic digestion for biogas production (methane rich gas) is a well established technology perfectly suited for FW management. Interest in anaerobic digestion (AD) has been continuously growing over the last decades, being more and more frequently promoted by national programmes for energy production from renewable resources (Clarke and Alibardi, 2010). Possibilities for biogas production from FW were recently reviewed by Kiran et al. (2014), with Kondusamy and Kalamdhad (2014), Pham et al. (2015) and Zhang et al. (2015) highlighting the potentials for renewable energy production from anaerobic treatment of FW. Anaerobic digestion is a mature technology that can be applied to almost all types of biodegradable substrates as source separated organic fraction of municipal solid waste, agricultural or industrial food waste and food manufacturing residues. The potential of anaerobic digestion process has also recently been evaluated for the biological conversion of hydrogen and carbon dioxide of different origins into methane for energy storage purposes (Burkhardt et al., 2015) and as carbon capture strategy during digestion of FW or sewage sludge (Bajón Fernández et al., 2014). Anaerobic digestion therefore represents a flexible process that can be used as final conversion process in a biorefinery chain for all those substrates and residual flows not further convertible to high value products. AD processes are also considered to be the best option for the biological production of hydrogen, one of the most interesting and promising biofuels (Guo et al., 2010; Ozkan et al., 2010; De Gioannis et al., 2013).

Several substrates have been evaluated as potentially suitable for biohydrogen generation through dark fermentation. Amongst these, FW may represent relatively inexpensive and ideal sources of biodegradable organic matter for H_2 production, mainly due to the high carbohydrate content and wide availability. Dark fermentation of FW can also be combined with other bioprocesses to maximise energy conversion (Alibardi et al., 2014; Kiran et al., 2014; De Gioannis et al., 2013). Dark fermentation process performances are affected by several aspects as the type and treatment of inoculum, type of reactor, organic loading rate and hydraulic retention time, process temperature and pH conditions (Wang and Wan, 2009; Guo et al., 2010; Nanqi et al., 2011). Different process conditions and specific aspects of the dark fermentation process have been analysed, although the results remain controversial, at times lacking direct comparability and at times being divergent or even antithetic (De Gioannis et al., 2013). Cappai et al. (2014) recently reported an optimal pH of 6.5 for hydrogen production from FW while at pH of 5.5, commonly assumed as the optimum, minimum hydrogen productions were recorded. Alibardi and Cossu (2015) demonstrated how changes in FW waste composition markedly affect hydrogen potential productions explaining the high variability of data reported in literature on FW. Favaro et al. (2013) reported good capacity of indigenous microflora of FW to produce biohydrogen. De Gioannis et al. (2014) measured significant fermentative biohydrogen productions from different types of cheese whey at pH values between 6.5 and 7.5, with the highest productions up to 170 mlH_2/kgTOC.

Pyrolysis and gasification are thermal processes viewed as alternatives to combustion in waste management (Pham et al., 2015). Pyrolysis of food waste, using temperatures between 400 and 800 °C, converts the material from the solid state into liquid products (so-called pyrolysis oil) and/or gas (syngas), which can be used as fuels or raw materials intended to subsequent chemical processes. The solid carbon residues can be further refined by providing products such as activated carbon. The products of pyrolysis are therefore gaseous, liquid and solid and their proportion depends upon the pyrolysis method and the reaction parameters.

Gasification partially oxidises food waste to produce a combustible gas mixture. Temperatures typically range between 800° and 900 °C. The gas produced can be burnt directly or used as a fuel for gas engines and gas turbines or used as a feedstock in the production of chemicals (e.g. methanol) (Pham et al., 2015).

Applicability and feasibility of these processes are strongly dependent on waste characteristics such as elemental composition, heating values, ash, moisture and volatile solids content, the presence of contaminants, bulk density. These characteristics are crucial for process performances and limit the applicability of gasification and pyrolysis to FW. The majority of gasification technologies for example use pre-treated waste as feedstocks and no gasification/pyrolysis processes have been developed using raw food waste (Arena, 2012; Pham et al., 2015). Only few researches were published on gasification or pyrolysis of food waste. Liu et al. (2014) investigated the effectiveness of catalytic pyrolysis of food waste by using microwave power for heating. These Authors reported an energy ratio of production to consumption (ERPC) of 0.91 without the use of catalysts. $CuCl_2$ or MnO_2 were added as catalysts, ERPC increased to 2.04 and 1.93, respectively. Bio-char (solid product) was in all cases the main energetic product of pyrolysis while bio-oil or gases yields were variable being the conversions into gaseous or liquid products competing processes (Liu et al., 2014). Opatokun et al. (2015) evaluated the pyrolysis of both dry raw FW and digested FW after biological anaerobic treatment and concluded that both substrates demonstrated potential for fast degradation due to high volatile matter content. Energy content was for both cases mainly spread into biochar and bio-oil fractions while gases provided significantly lower energy.

The impact of pre-treatments and drying processes on overall energy production is still not clear thus FW water content seems to remain the limiting characteristic of these processes. Processes not requiring a drying step are hydrothermal water gasification or hydrothermal carbonisation as both utilise water as the main reaction medium and reactant. Hydrothermal (subcritical and supercritical water) gasification can generate hydrogen gas from biodegradable wastes. Muangrat et al. (2012) investigated the effect of carbohydrate, protein and lipid proportions in several FW samples for hydrogen production by using subcritical water gasification and reported that carbohydrate-rich samples were preferred for the reaction conditions applied as protein and lipid promoted side reactions of neutralisation and saponification, respectively.

Hydrothermal carbonisation (HTC) is a thermal treatment technique used to convert food wastes and associated packaging materials to a valuable, energy-rich resource. HTC is attracting increased attention from researchers, especially for waste streams with high moisture content (80–90%) (Pham et al., 2015; Li et al., 2013). HTC was applied to several organic wastes, at different operating conditions, temperature ranges (200–350 °C) and process duration (0.2–120 h) (i.a. Pham et al., 2015). Results demonstrated that food waste could be beneficially treated by HTC resulting in the production of hydrochar with high carbon and energy. Lin et al. (2013) reported positive energy balances on HTC treatment of food waste collected from local restaurants. The presence of packaging materials may influence the energy content of the recovered solids. The higher the presence of packaging materials, the lower the energy content of recovered solids due to the low energetic retention associated with the packaging materials (Lin et al., 2013).

3.2. Biomaterials production

The challenge of finite fossil resources has been addressed by academic and industrial researchers with the development of valuable compounds and polymers based on renewable resources (besides the previously mentioned biofuels). The use of agro-industrial residues for the extraction of high-value chemicals was recently reviewed by Mirabella et al. (2014). Biopolymers production is a possibility facing growing interest as it is applicable both to agro-industrial residues and organic waste from household level. The corresponding monomers are accessible either through fermentation of carbohydrate feedstocks by microbes, often genetically modified, or by chemical processing of plant oils (Fuessl et al., 2012). The production of biological metabolites to be used as renewable and biodegradable substitutes for petrochemical products is currently the focus of growing interest. These metabolites are: lactate for the production of polylactate, a plastic constituent; polyhydroxyalkanotes, particularly polyhydroxybutyrate, which are natural storage polymer of many bacterial species with properties similar to polyethylene and polypropylene; succinate, a valuable and flexible precursor for pharmaceutical, plastic and detergent production (Hassan et al., 2013; Sulaiman et al., 2014; Li et al., 2015). As for the biofuel production from virgin feedstocks, considerable debate surrounds the manufacture of bioplastics from natural materials, raising the issue as to whether they produce a negative impact on human food supply. In this context, the opportunity of using waste food in the production of bio-plastics seems a highly feasible option.

Bio-production of optically pure L-lactic acid from food waste has attracted considerable interest due to its ability to treat organic wastes with simultaneous recovery of valuable by-products (Li et al., 2015). A new strategy was reported for effective production of optically pure L-lactic acid from food waste at ambient temperature, regulating key enzyme activity by sewage sludge supplementation and intermittent alkaline fermentation. A production of optically pure L-lactic acid was achieved from food waste at ambient temperature with a yield of 0.52 g/gCOD (Li et al., 2015).

Dairy industries generate high amounts of whey from milk processing for various manufactured products. Whey is a by-product discharged by the cheese production process, and its disposal is currently a major pollution problem for the dairy industry (Abdel-Rahman et al., 2013). Whey is a potent and suitable raw material for lactic acid production, consisting in lactose, proteins, fats, water-soluble vitamins, mineral salts, and other essential nutrients for microbial growth (Panesar et al., 2007). Theoretically, 4 mol of lactic acid can be produced from 1 mol of lactose through a homofermentative pathway following the cleavage of lactose to 1 mol of glucose and 1 mol of galactose (Abdel-Rahman et al., 2013). The market for yogurt has also grown rapidly over the past few years. Consequently, damaged or expired yogurts create huge amounts of waste products. Yogurt is usually sweetened with additional sugars, such as sucrose and glucose, which would result in higher lactic acid production than cheese whey containing fewer sugars.

At present, amongst the various types of starch-based biodegradable plastics such as polylactic acid (PLA) and polyvinyl acetate (PVA), the group of polyhydroxyalkanoates (PHAs) is one of the most promising. Polyhydroxyalkanoates (PHAs) are linear polyesters of hydroxyacids (hydroxyalkanoate monomers) synthesised by a wide variety of bacteria through bacterial fermentation (Reis et al., 2011). The strength and toughness of PHAs are good, and they are completely resistant to moisture and feature a very low oxygen permeability. Accordingly, PHA is suitable for use in the production of bottles and water resistant film (Van Wegen et al., 1998). The simplest type of PHA is polyhydroxybutyrate (PHB). The majority of bacteria synthesising PHAs can be broadly subdivided into two groups. One group produces short-chain-length PHAs (SCL-PHAs) with monomers ranging from 3 to 5 carbons in length, while a distinct group synthesises medium-chain-length PHAs (MCL-PHAs) with monomers from 6 to 16 carbons. PHAs accumulate in bacteria cytoplasm as a high molecular weight polymer forming intracellular granules of 0.2–0.7 mm in diameter. Typically, PHAs accumulate to a significant proportion of the cell dry weight when bacteria are grown in a media that is limited in a nutrient essential for growth (typically nitrogen or phosphorus), but with an abundant supply of carbon (for example glucose). Under these conditions, bacteria convert the extracellular carbon into an intracellular storage form, namely PHA. When the limiting nutrient is resupplied, intracellular PHA is degraded and the resulting carbon is used for growth (Reis et al., 2011).

The main limitation in using bacterial PHAs as a source of biodegradable polymers is their production cost. In particular the average cost is by far the most significant contributor to overall PHB price, approximately two and a quarter times greater than the capital cost of equipment (Van Wegen et al., 1998). Using agro-industrial food waste as substrate instead of virgin feedstock of refined sugar such as glucose, sucrose and corn steep liquor could represent a turning point. Sugarcane and beet molasses, cheese whey effluents, plant oils, swine waste liquor, vegetable and fruit wastes, effluents of palm oil mill, olive oil mill, paper mill, pull mill and hydrolysates of starch (e.g., corn and tapioca), cellulose and hemicellulose are all excellent alternatives characterised by a high organic fraction (Reis et al., 2011).

A three-stage biotechnological process proposed by Reis et al. (2011) demonstrated good potential for PHA production from waste/surplus-based feedstocks using enriched mixed cultures. The basic concept was based on an initial acidogenic fermentation phase of the feedstock, a second phase of selection and production of PHA-storing bacterial biomass under dynamic feeding, and the last phase in which PHA was accumulated in batch conditions. It is important to underline the main role played by the initial acidogenic fermentation stage needed to overcome the weak point of the process represented by the fact that most waste and surplus feedstocks contain several organic compounds that are not equally suitable for PHA production. Carbohydrates in fact are not stored by mixed cultures as PHA, but rather as glycogen. Thus, acidogenic fermentation is an essential stage to increase the potential of producing PHA by mixed cultures from surplus-based feedstocks. Carbohydrates and other compounds are, in this way, transformed into VFA that are readily convertible into PHA (Reis et al., 2011).

As assessed by Koller et al. (2013), PHAs and their follow-up products can be processed to create a broad range of marketable products for a variety of applications. They have potential in agro-industrial applications (carriers and matrices for controlled release of nutrients, fertilisers and pesticides), therapeutic applications (controlled release of active pharmaceutical ingredients), in buildings blocks, in packaging materials and surgical implants. Naranjo et al. (2014) investigated the integrated production of PHB and ethanol from banana residues as agro-industrial waste. PHB production was carried out using the glucose obtained in the hydrolysis stage from banana pulp, while peels were exploited for ethanol production. The theoretical yields of PHB and ethanol were 31.5 and 238 kg/ton bananas, respectively. Other food waste used for PHA production were fruit pomace and waste frying oil (Follonier et al., 2014), spent coffee grounds (Obruca et al., 2014), distillery spent wash (Amulya et al., 2014), and margarine waste (Morais et al., 2014). Zhang et al. (2014) evaluated how PHA composition is influenced by ratio of even-numbered to odd-numbered VFAs from co-treatment of food waste and sewage sludge. The consumption of even-numbered VFAs was correlated with the PHB synthesis, while the consumption of odd-numbered VFAs was correlated with the synthesis of polyhydroxyvalerate (PHV). The relatively constant quality and fermentable sugar content characterise food waste as an ideal substrate for PHAs production.

As already highlighted for dark fermentation, interconnections of biotechnological processes for the co-production of bio-fuels and bio-products therefore represent a key strategy in maximising food waste utilisation and potential income of the entire bioprocess chain (Venkateswar Reddy et al., 2014). Lin (2012) demonstrated for example that microalgae can grow on pure food waste hydrolysate without any negative effects on growth or biomass composition. The outcomes open up for an economically feasible cultivation of heterotrophic microalgae based on mixed food waste hydrolysate and a use of microalgal biomass for a production of biofuels and platform chemicals. In this way it would be possible to weave a complex and elaborate scheme leading at maximising the yield within the FW biorefinery concept.

4. Conclusions

The development of sustainable solutions for food waste management represents one of the main challenges for society. These solutions should be capable of exploiting the precious resources represented by food waste to achieve social, economical and environmental benefits. The development of sustainable solutions for food waste management represents one of the main challenges for society. These solutions should be capable of exploiting the precious resources represented by food waste to achieve social, economical and environmental benefits. Clear and generally accepted definitions of food waste and related terms are anyway still missing and estimations on generated amounts are not yet consolidated. Avoidance of food waste generation could be ideally obtained by a proper equilibrium between food production and consumption, but such an optimum arranging is still far from being attained. A feasible management of excess production of edible food consists in its redistribution to feed poor people. The practice of food donation needs to find support from governments to facilitate the recovery and redistribution by food banks or social services. Agro-industrial residues and household food waste no longer suitable for human consumption can be used as feedstocks for the production of bio-plastics and bio-fuels together with the extraction of high-value components. This requires active participation from the public as well, in order to end up with a properly segregated FW to be transformed into resource. Practical and convenient solutions hand in hand with proper information campaigns targeted accordingly the area of interest need to be designed. Similar to the production of biofuel from virgin feedstocks, considerable debate surrounds the manufacture of bioplastics from natural materials, raising the issue as to whether they produce a negative impact on human food supply. In this context, the opportunity of using food waste as a feedstock in the production of bio-fuels and bio-plastics seems a feasible option. To conclude therefore, the interconnection of biotechnological processes in the co-production of bio-fuels and bio-products represents a key strategy aimed at maximising the utilisation of food waste and raising the potential income of the entire bioprocess chain.

References

Abdel-Rahman, M.A., Tashiro, Y., Sonomoto, K., 2013. Recent advances in lactic acid production by microbial fermentation processes. Biotech. Adv. 31 (6), 877–902.
Aiello, G., Enea, M., Muriana, C., 2014. Economic benefits from food recovery at the retail stage: an application to Italian food chains. Waste Manage. 34 (7), 1306–1316.
Alexander, C., Smaje, C., 2008. Surplus retail food redistribution: an analysis of a third sector model. Resour. Conserv. Recycl. 52, 1290–1298.
Alibardi, L., Cossu, R., 2015. Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials. Waste Manage. 36, 147–155.
Alibardi, L., Muntoni, A., Polettini, A., 2014. Hydrogen and waste: illusions, challenges and perspectives. Waste Manage. 34, 2425–2426.
Alptekin, E., Canakci, M., Sanli, H., 2014. Biodiesel production from vegetable oil and waste animal fats in a pilot plant. Waste Manage. 34 (11), 2146–2154.
Amulya, K., Venkateswar Reddy, M., Venkata Mohan, S., 2014. Acidogenic spent wash valorization through polyhydroxyalkanoate (PHA) synthesis coupled with fermentative biohydrogen production. Bioresource Technol. 158, 336–342.
Ando, A.W., Gosselin, A.Y., 2005. Recycling in multifamily dwellings: does convenience matter? Econ. Inq. 43 (2), 426–438.
Arena, U., 2012. Process and technological aspects of municipal solid waste gasification. A Review. Waste Manage. 32, 625–639.
Arumugam, R., Manikandan, M., 2011. Fermentation of pretreated hydrolyzates of banana and mango fruit wastes for ethanol production. Asian J. Exp. Biol. Sci. 2, 246–256.
Bajón Fernández, Y., Soares, A., Villa, R., Vale, P., Cartmell, E., 2014. Carbon capture and biogas enhancement by carbon dioxide enrichment of anaerobic digesters treating sewage sludge or food waste. Bioresource Technol. 159, 1–7.

Barr, S., Gilg, A.W., 2005. Conceptualising and analysing household attitudes and actions to a growing environmental problem: development and application of a framework to guide local waste policy. Appl. Geogr. 25 (3), 226–247.

Bello, R.H., Linzmeyer, P., Franco, C.M.B., Souza, O., Sellin, N., Medeiros, S.H.W., Marangoni, C., 2014. Pervaporation of ethanol produced from banana waste. Waste Manage. 34 (8), 1501–1509.

Bernstad, A., 2014. Household food waste separation behaviour and the importance of convenience. Waste Manage. 34 (7), 1317–1323.

Bernstad, A., la Cour Jansen, J., 2011. A life cycle approach to the management of household food waste – a Swedish full-scale case study. Waste Manage. 31 (8), 1879–1896.

Betz, A., Buchli, J., Göbel, C., Müller, C., 2015. Food waste in the Swiss food service industry – magnitude and potential for reduction. Waste Manage. 35 (1), 218–226.

Beylot, A., Villeneuve, J., Bellenfant, G., 2013. Life Cycle Assessment of landfill biogas management: sensitivity to diffuse and combustion air emissions. Waste Manage. 33, 401–411.

Burkhardt, M., Koschack, T., Busch, G., 2015. Biocatalytic methanation of hydrogen and carbon dioxide in an anaerobic three-phase system. Bioresource Technol. 178, 330–333.

Buzby, J.C., Hyman, J., 2012. Total and per capita value of food loss in the United States. Food Policy 37, 561–570.

Canakci, M., 2007. The potential of restaurant waste lipids as biodiesel feedstocks. Bioresource Technol. 98, 183–190.

Cappai, G., De Gioannis, G., Friargiu, M., Massi, E., Muntoni, A., Polettini, A., Pomi, R., Spiga, D., 2014. An experimental study on fermentative H2 production from food waste as affected by pH. Waste Manage. 34, 1510–1519.

Cekmecelioglu, D., Uncu, O.N., 2013. Kinetic modelling of enzymatic hydrolysis of pretreated kitchen wastes for enhancing bioethanol production. Waste Manage. 33 (3), 735–739.

Clarke, W.P., Alibardi, L., 2010. Anaerobic digestion for the treatment of solid organic waste: what's hot and what's not. Waste Manage. 30, 1761–1762.

Cossu, R., 2009. From triangles to cycles. Waste Manage. 29, 2915–2917.

Cossu, R., 2012. The environmentally sustainable geological repository: the modern role of landfilling. Waste Manage. 32, 243–244.

Curran, T., Williams, I.D., 2012. A zero waste vision for industrial networks in Europe. J. Hazard. Mater. 207–208, 3–7.

De Gioannis, G., Muntoni, A., Polettini, A., Pomi, R., 2013. A review of dark fermentative hydrogen production from biodegradable municipal waste fractions. Waste Manage. 33, 1345–1361.

De Gioannis, G., Friargiu, M., Massi, E., Muntoni, A., Polettini, A., Pomi, R., Spiga, D., 2014. Biohydrogen production from dark fermentation of cheese whey: influence of pH. Int. J. Hydrogen Energy 39, 20930–20941.

Dee, J., 2013. Australia needs a food waste strategy. ABC Environment. <http://www.abc.net.au/environment/articles/2013/06/05/3774785.htm>.

EC, 2010. Preparatory study on food waste across EU 27. European Commission. <http://ec.europa.eu/environment/archives/eussd/pdf/bio_foodwaste_report.pdf>.

EC, 2013. Food waste in Europe. European Commission. <http://ec.europa.eu/dgs/health_food-safety/information_sources/docs/speeches/speech-food-waste-expo-07022013_en.pdf>.

Echevarria, S., Santos, R., Waxman, E., Engelhard, E., Del Vecchio, T., 2011. Food Banks: Hunger's New Staple. A report on Visitation Patterns and Characteristics of Food Pantry Clients in the United States in 2009. Feeding America. Chicago. USA.

EESC, 2014. Comparative Study on EU Member States' legislation and practices on food donation, Final Report. BIO by Deloitte. <http://www.eesc.europa.eu/resources/docs/comparative-study-on-eu-member-states-legislation-and-practices-on-food-donation_finalreport_010714.pdf>.

EPA, 2014. Environmental Protection Agency. <http://www.epa.gov/foodrecovery/>.

Eriksson, M., Strid, I., Hansson, P.-A., 2014. Waste of organic and conventional meat and dairy products – a case study from Swedish retail. Resour. Conserv. Recycl. 83, 44–52.

European Food Banks, 2007. Consolidated activity of food banks members of the European Federation of Food Banks, Bourg-la-Reine.

FAO, 1981. Food loss prevention in perishable crops. FAO Agricultural Services Bulletin 43, Rome, 72.

Favaro, L., Alibardi, L., Lavagnolo, M.C., Casella, S., Basaglia, M., 2013. Effects of inoculum and indigenous microflora on hydrogen production from the organic fraction of municipal solid waste. Int. J. Hydrogen Energy 38, 11774–11779.

FEBA, n.a. Against hunger and food waste in Europe. European Federation of Food Banks. <http://www.eurofoodbank.eu/portail/index.php?lang=en>.

Follonier, S., Goyder, M.S., Silvestri, A.-C., Crelier, S., Kalman, F., Riesen, R., Zinn, M., 2014. Fruit pomace and waste frying oil as sustainable resources for the bioproduction of medium-chain-length polyhydroxyalkanoates. Int. J. Biol. Macromol. 71 (2014), 42–52.

Fuessl, A., Yamamoto, M., Schneller, A. 2012. Opportunities in bi-based building blocks for polycondensates and vinyl polymers. Polymer Science: A Comprehensive Reference, Elsevier, vol. 5, pp. 49–70.

Galanakis, C.M., 2012. Recovery of high added-value components from food wastes: conventional, emerging technologies and commercialized applications. Trends Food Sci. Tech. 26, 68–87.

Garrone, P., Melacini, M., Perego, A., 2014. Opening the black box of food waste reduction. Food Policy 46, 129–139.

Gasparatos, A., Stromberg, P., Takeuchi, K., 2011. "Biofuels, ecosystem services and human wellbeing: putting biofuels in the ecosystem services narrative". Agriculture. Ecosyst. Environ. 142, 111–128.

Ghanavati, H., Nahvi, I., Karimi, K., 2015. Organic fraction of municipal solid waste as a suitable feedstock for the production of lipid by oleaginous yeast *Cryptococcus aerius*. Waste Manage. 38, 141–148.

Glanz, R., Schneider, F., 2009. Causes of food waste generation in household. In: Proceedings Sardinia 2009, Twelfth International Waste Management and Landfill Symposium. S. Margherita di Pula, Cagliari. CISA Publisher, Italy.

GMA, 2012. Grocery Manufacturers Association. Food Waste: Tier 1 Assessment. <http://www.foodwastealliance.org/wp-content/uploads/2013/06/FWRA_BSR_Tier1_FINAL.pdf>.

Gonçalves Filho, L.C., Fischer, G.A.A., Sellin, N., Marangoni, C., Souza, O., 2013. Hydrolysis of banana tree pseudostem and second-generation ethanol production by saccharomyces cerevisae. Bioresour. Technol. 2, 65–69.

Graefe, S., Dufour, D., Giraldo, A., Muñoz, L.A., Mora, P., Solís, H., Garcés, H., Gonzalez, A., 2011. Energy and carbon footprints of ethanol production using banana and cooking banana discard: a case study from Costa Rica and Ecuador. Biomass Bioenergy 35, 2640–2649.

Graham-Rowe, E., Jessop, D.C., Sparks, P., 2014. Identifying motivations and barriers to minimising household food waste. Resour. Conserv. Recycl. 84, 15–23.

Guo, X.M., Trably, E., Latrille, E., Carrere, H., Steyer, J.-P., 2010. Hydrogen production from agricultural waste by dark fermentation: a review. Int. J. Hydrogen Energy 35, 10660–10673.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A., 2011. Global food losses and food waste. Extent, causes and prevention. Rome.

Hassan, M.A., Yee, L.N., Yee, P.L., Ariffin, H., Raha, A.R., Shirai, Y., Sudesh, K., 2013. Sustainable production of polyhydroxyalkanoates from renewable oil-palm biomass. Biomass Bioenergy 50, 1–9.

Hossain, A.B.M.S., Ahmed, S.A., Ahmed, M.A., Faris, M.A.A., Annuar, M.S.M., Hadeel, M., Norah, H., 2011. Bioethanol fuel production from rotten banana as an environmental waste management and sustainable energy. Afr. J. Microbiol. Res. 5, 586–598.

Hou, L., 2013. South Korea's food waste solution: you waste, you pay. Common Wealth Mag. <http://english.cw.com.tw/article.do?action=show&id=14067>.

Katajajuuri, J.M., Silvennoinen, K., Hartikainen, H., Heikkila, L., Reinikainen, A., 2014. Food waste in the Finnish food chain. J. Clean. Production. http://dx.doi.org/10.1016/j.jclepro.2013.12.057.

Kim, J.H., Lee, J.C., Pak, D., 2011. Feasibility of producing ethanol from food waste. Waste Manage. 31 (9), 2121–2125.

Kiran, E.U., Trzcinski, A.P., Ng, W.J., Liu, Y., 2014. Bioconversion of food waste to energy: a review. Fuel 134, 389–399.

Kojima, R., Ishikawa, M., 2013. Prevention and Recycling of Food Wastes in Japan: Policies and Achievements. Kobe University, Japan, Resilent cities.

Koller M., Salerno A., Braunegg, G., 2013. Polyhydroxyalkanoates: basics, production and applications of microbial biopolyesters. Bio-based Plastics: Materials and Applications. Wiley, New York, 137–170.

Kondusamy, D., Kalamdhad, A.S., 2014. Pre-treatment and anaerobic digestion of food waste for high rate methane production – a review. J. Environ. Chem. Eng. 2, 1821–1830.

Lebersorger, S., Schneider, F., 2014. Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. Waste Manage. 34 (11), 1911–1919.

Levis, J.W., Barlaz, M.A., Themelis, N.J., Ulloa, P., 2010. Assessment of the state of food waste treatment in the United States and Canada. Waste Manage. 30 (8–9), 1486–1494.

Li, Q., Zheng, L., Cai, H., Garza, E., Yu, Z., Zhou, S., 2011. From organic waste to biodiesel: Black soldier fly, *Hermetia illucens*, makes it feasible. Fuel 90, 1545–1548.

Li, L., Diederick, R., Flora, J.R.V., Berge, N.D., 2013. Hydrothermal carbonization of food waste and associated packaging materials for energy source generation. Waste Manage. 33 (11), 2478–2492.

Li, X., Chen, Y., Zhao, S., Chen, H., Zheng, X., Luo, J., Liu, Y., 2015. Efficient production of optically pure l-lactic acid from food waste at ambient temperature by regulating key enzyme activity. Water Res. 70, 148–157.

Lin, C.S.K., 2012. Development of food waste-based biorefineries for the production of biodegradable plastics and platform chemicals. J. Food Process. Technol. 3, 112.

Lin, J., Zuo, J., Gan, L., Li, P., Liu, F., Wang, K., Gan, H., 2011. Effects of mixture ratio on anaerobic co-digestion with fruit and vegetable waste and food waste of China. J. Environ. Sci. 23 (8), 1403–1408.

Lin, C.S.K., Pfaltzgraff, L.A., Herrero-Davila, L., Mubofu, E.B., Abderrahim, S., Clark, J.H., Koutinas, A.A., Kopsahelis, N., Stamatelatou, K., Dickson, F., Thankappan, S., Mohamed, Z., Brocklesbyc, R., Luque, R., 2013. Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective. Energy Environ. Sci. 6, 426–464.

Lipinski, B, Hanson, C., Lomax, J., Kitinoja, L., Waite, R., Searchinger, T., 2013. Reducing food loss and waste. Installment 2 of Creating a Sustainable Food Future, World Resources Institute, Washington DC.

Liu, H., Ma, X., Li, L., Hu, Z., Guo, P., Jiang, Y., 2014. The catalytic pyrolysis of food waste by microwave heating. Bioresource Technol. 166, 45–50.

Manfredi, S., Tonini, D., Christensen, T.H., 2010. Contribution of individual waste fractions to the environmental impacts from landfilling of municipal solid waste. Waste Manage. 30, 433–440.

Mena, C., Terry, L.A., Williams, A., Ellram, L., 2014. Causes of waste across multi-tier supply networks: Cases in the UK food sector. Int. J. Prod. Econ., <http://dx.doi.org/10.1016/j.ijpe.2014.03.012>
Mirabella, N., Castellani, V., Sala, S., 2014. Current options for the valorization of food manufacturing waste: a review. J. Clean. Prod. 65, 28–41.
Morais, C., Freitas, F., Cruz, M.V., Paiva, A., Dionísio, M., Reis, M.A.M., 2014. Conversion of fat-containing waste from the margarine manufacturing process into bacterial polyhydroxyalkanoates. Int. J. Biol. Macromol. 71, 68–73.
Muangrat, R., Onwudili, J.A., Williams, P.T., 2012. Reactions of different food classes during subcritical water gasification for hydrogen gas production. Int. J. Hydrogen Energy 37, 2248–2259.
Nahman, A., de Lange, W., 2013. Costs of food waste along the value chain: Evidence from South Africa. Waste Manage. 33 (11), 2493–2500.
Nanqi, R., Wanqian, G., Bingfeng, L., Guangli, C., Jie, D., 2011. Biological hydrogen production by dark fermentation: challenges and prospects towards scaled-up production. Curr. Opin. Biotech. 22, 365–370.
Naranjo, J.M., Cardona, C.A., Higuita, J.C., 2014. Use of residual banana for polyhydroxybutyrate (PHB) production: Case of study in an integrated biorefinery. Waste Manage. 34 (12), 2634–2640.
Nelles, M., Arena, U., Bilitewski, B., 2010. Thermal waste treatment – an essential component of a sustainable waste treatment system. Waste Manage. 30, 1159–1160.
Nellman, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A.G., 2009. The Environmental Food Crisis – The Environment's Role in Averting Future Food Crises. United Nations Environment Program (UNEP), Norway.
Oberoi, H.S., Vadlani, P.V., Saida, L., Bansal, S., Hughes, J.D., 2011. Ethanol production from banana peels using statistically optimized simultaneous saccharification and fermentation process. Waste Manage. 31, 1576–1584.
Obruca, S., Benesova, P., Petrik, S., Oborna, J., Prikryl, R., Marova, I., 2014. Production of polyhydroxyalkanoates using hydrolysate of spent coffee grounds. Process Biochem. 49, 1409–1414.
Opatokun, S.A., Strezov, V., Kan, T., 2015. Product based evaluation of pyrolysis of food waste and its digestate. Energy. http://dx.doi.org/10.1016/j.energy.2015.02.098.
Östergren, K., Gustavsson, J., Bos-Brouwers, H., Timmermans, T., Hansen, O-J., Møller, H., Anderson, G., O'Connor, C., Soethoudt, H., Quested, T., Easteal, S., Politano, A., Bellettato, C., Canali, M., Falasconi, L., Gaiani, S., Vittuari, M., Schneider, F., Moates, G., Waldron, K., Redlingshöfer, B., 2014. FUSIONS Definitional Framework for Food Waste. Full Report. 3 July 2014. ISBN 978-91-7290-331-9.
Ozkan, L., Erguder, T.H., Demirer, G.N., 2010. Investigation of the effect of culture type on biological hydrogen production from sugar industry wastes. Waste Manage. 30, 792–798.
Panesar, P.S., Kennedy, J.F., Gandhi, D.N., Bunko, K., 2007. Bioutilisation of whey for lactic acid production. Food Chem. 105, 1–14.
Papargyropoulou, E., Lozano, R., Steinberger, J., Wright, N., Bin Ujang, Z., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J. Clean. Prod. http://dx.doi.org/10.1016/j.jclepro.2014.04.020.
Parfitt, J., Barthel, M., Macnaughton, S., 2010. Food waste within food supply chains: quantification and potential for change to 2050. Phil. Trans. R. Soc. 365, 3065–3081.
Parizeau, K., von Massow, M., Martin, R., 2015. Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph. Ontario. Waste Manage. 35 (1), 207–217.
Pfaltzgraff, L.A., De bruyn, M., Cooper, E.C., Budarin, V., Clark, J.H., 2013. Food waste biomass: a resource for high-value chemicals. Green Chem. 15, 307–3014.
Pham, T.P.T., Kaushik, R., Parshetti, G.K., Mahmood, R., Balasubramanian, R., 2015. Food-waste-to-energy conversion technologies: current status and future directions. Waste Manage. 38, 399–408.
Pirozzi, D., Ausiello, A., Yousuf, A., 2012. Exploitation of Lignocellulosic Materials for the Production of II Generation Biodiesel. In: Proceesing Venice 2012, Fourth International Symposium on Energy from Biomass and Waste. Cini Foundation, Venice Italy. CISA Publisher, Italy.
Quested, T.E., Marsh, E., Stunell, D., Parry, A.D., 2013. Spaghetti soup: the complex world of food waste behaviours. Resour. Conserv. Recycl. 79, 43–51.
Refaat, A.A., 2012. Biofuels from Waste Materials. J. Compr. Renew. Energy 5, 217–261.
Reis, M, Albuquerque, M., Villano, M, Majone, M., 2011. Mixed culture processes for polyhydroxyalkanoate production from agro-industrial surplus/wastes as feedstocks. Compr. Biotech., vol. 6, 2nd ed, 669–683.
Rousta, K., Bolton, K., Lundin, M., Dahlén, L., 2015. Quantitative assessment of distance to collection point and improved sorting information on source separation of household waste. Waste Manage. 40, 22–30.
Sarkar, N., Ghosh, S.K., Bannerjee, S., Aikat, K., 2012. Bioethanol production from agricultural wastes: an overview. Renew. Energy 37 (1), 19–27.
Scherhaufer, S., Schneider, F., 2011. Prevention, recycling and disposal of waste bread in Austria. In: Proceedings Sardinia 2011, Thirteenth International landfill Symposium, CISA publisher, Cagliari.
Schneider, F., 2013a. The evolution of food donation with respect to waste prevention. Waste Manage. 33 (3), 755–763.
Schneider, F., 2013b. Review of food waste prevention on an international level. Water Resour. Manage. 166, 187–203.
Schneider, F., Lebersorger, S., 2009. Household attitudes and behaviour towards wasting food – A case study. In: Proceedings Sardinia 2009, Twelfth International Waste Management and Landfill Symposium. S. Margherita di Pula, Cagliari. CISA Publisher, Italy.
Silvennoinen, K., Katajajuuri, J.M., Hartikainen, H., Jalkanen, L., Koivupuro, H.K., Reinikainen, A., 2012. Food waste volume and composition in the Finnish supply chain: special focus on food service sector. In: Proceesing Venice 2012, Fourth International Symposium on Energy from Biomass and Waste. Cini Foundation, Venice Italy. CISA Publisher, Italy.
Smil, V., 2004. Improving efficiency and reducing waste in our food system. Environ. Sci. 1, 17–26.
Stoeberl, M., Werkmeistera, R., Faulstichb, M., Russa, W., 2011. Biobutanol from food wastes – fermentative production, use as biofuel an the influence on the emissions. Procedia Food Waste 1, 1868–1974.
Sulaiman, A., Othman, N., Baharuddin, A.S., Mokhtar, M.N., Tabatabaei, M., 2014. Enhancing the halal food industry by utilizing food wastes to produce value-added bioproducts. Procedia-Soc. Behav. Sci. 121, 35.
Thi, N.B.D., Kumar, G., Lin, C.Y., 2015. An overview of food waste management in developing countries: current status and future perspective. J. Environ. Manage. 157, 220–229.
Thomsen, N.I., Milosevic, N., Bjerg, P.L., 2012. Application of a contaminant mass balance method at an old landfill to assess the impact on water resources. Waste Manage. 32, 2406–2417.
Timilsina, G.R., Shrestha, A., 2011. How much hope should we have for biofuels? Energy 36 (4), 2055–2069.
Tuck, C.O., Pérez, E., Horvath, I.T., Sheldon, R.A., Poliakoff, R., 2012. Valorization of biomass: deriving more value from waste. Science 337, 695–699.
Ujor, V., Bharathidasan, A.K., Cornish, K., Ezeji, T.C., 2014. Feasibility of producing butanol from industrial starchy food wastes. Appl. Energy 136, 590–598.
Van Wegen, R.J., Ling, Y., Middelberg, A.P.J., 1998. Industrial production of polyhydroxyalkanoates using escherichia coli: an economic analysis. Trans IChemE 76, 417–426.
Vandermeersch, T., Alvarenga, R.A.F., Ragaert, P., Dewulf, J., 2014. Environmental sustainability assessment of food waste valorization options. Resour. Conserv. Recycl. 87, 57–64.
Venkateswar Reddy, M., Amulya, K., Rohit, M.V., Sarma, P.N., Venkata Mohan, S., 2014. Valorization of fatty acid waste for bioplastics production using Bacillus tequilensis: integration with dark-fermentative hydrogen production process. Int. J. Hydrogen Energy 39, 7616–7626.
Wan, A., Ghani, K., Rusli, I.F., Awang Biak, D.R., Idris, A., 2013. An application of the theory of planned behaviour to study the influencing factors of participation in source separation of food waste. Waste Manage. 33 (5), 1276–1281.
Wang, J., Wan, W., 2009. Factors influencing fermentative hydrogen production: a review. Int. J. Hydrogen Energy 34, 799–811.
Whitehair, K.J., Shanklin, C.W., Brannon, L.A., 2013. Written messages improve edible food waste behaviors in a university dining facility. J. Acad. Nutr. Diet. 113 (1), 63–69.
Williams, I.D., Schneider, F., Syversen, F., 2015. The "food waste challenge" can be solved. Waste Manage. 41, 1–2.
WRAP, 2013. Food Waste Reduction. <http://www.wrap.org.uk/food-waste-reduction>.
WRAP, 2015. Strategies to achieve economic and environmental gains by reducing food waste. <http://newclimateeconomy.report/wp-content/uploads/2015/02/WRAP-NCE_Economic-environmental-gains-food-waste.pdf>.
Yaakob, Z., Mohammad, M., Alherbawi, M., Alam, Z., Sopian, K., 2013. Overview of the production of biodiesel from waste cooking oil. Renew. Sustain. Energy Rev. 18, 184–193.
Youngs, A.J., Nobis, G., Town, P., 1983. Food waste from hotels and restaurants in the UK. Waste Manage. Res. 1 (1), 295–308.
Zhang, C., Su, H., Baeyens, J., Tan, T., 2014. Reviewing the anaerobic digestion of food waste for biogas production. Renew. Sustain. Energy Rev. 38, 383–392.
Zhou, W., 2013. Food Waste and Recycling in China: A Growing Trend? Worldwatch Institute. <http://www.worldwatch.org/food-waste-and-recycling-china-growing-trend-1>.