Egyptian Journal of Petroleum 27 (2018) 1275–1290

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Egyptian Journal of Petroleum

journal homepage: www.sciencedirect.com

Review

Solid waste issue: Sources, composition, disposal, recycling, and valorization

Hussein I. Abdel-Shafy [a], Mona S.M. Mansour [b,*]

[a] *Water Research & Pollution Control Department, National Research Centre, Dokki, Cairo, Egypt*
[b] *Analysis & Evaluation Department, Egyptian Petroleum Research Institute, 1 Ahmed El-Zomor Street, Nasr City Cairo, Egypt*

ARTICLE INFO

Article history:
Received 14 April 2018
Revised 20 June 2018
Accepted 8 July 2018
Available online 5 September 2018

Keywords:
Valorization of plastic and municipal solid wastes
Waste-to-energy
Organic solid state fermentation technology
Anaerobic digestion of organic solid wastes
Enhanced Landfill Mining

ABSTRACT

Disposal of solid wastes is a stinging and widespread problem in both urban and rural areas in many developed and developing countries. Municipal solid waste (MSW) collection and disposal is one of the major problems of urban environment in most countries worldwide today. MSW management solutions must be financially sustainable, technically feasible, socially, legally acceptable and environmentally friendly. Solid waste management issue is the biggest challenge to the authorities of both small and large cities'.

Valorization of food organic waste is one of the important current research areas. The conventional landfill, incineration, composting, and ways of handeling solid wastes are common as mature technologies for waste disposal. Traditionally, the most commonly used technologies for the treatment and valorization of the organic fraction of MSW are composting and anaerobic digestion (AD). The generation of organic solid waste (OSW); worldwide; is dramatically increasing each year. Most of the OSW's are composed of agricultural waste, household food waste, human and animal wastes, etc. They are normally handled as animal feed, incinerated or disposed to landfill sites. OAW's are comprised of materials rich in proteins, minerals, and sugars that could be used in other processes as substrates or raw materials.

Contents

Abbreviations: MSW, municipal solid waste; EPA, Environmental Protection Agency; SWG, solid waste generation; HHW, household hazardous wastes; HW, household waste; BOD, biochemical oxygen demand; MC, moisture content; GHGs, greenhouse gases; BTEX, benzene, toluene, ethylbenzene, and xylenes; FTIR, Fourier Transform Infrared Spectroscopy; OFMSW, organic fraction of municipal solid waste; AD, anaerobic digestion; MOW, municipal organic waste; SSF, solid state fermentation; PHB, poly-3-hydroxybutyrate; Bt, *Bacillus thuringiensis*; OM, organic matter; WWTPs, wastewater treatment plants; EWM, enhanced waste management; ELFM, Enhanced Landfill Mining; WtE, waste-to-energy; WtP, waste-to-product; RDF, refuse derived fuel; ISWM, Integrated sustainable waste management; SmF, submerged fermentation; IAA, integrated agriculture-aquaculture.

Peer review under responsibility of Egyptian Petroleum Research Institute.

* Corresponding author.
E-mail address: m.mansour@epri.sci.eg (M.S.M. Mansour).

https://doi.org/10.1016/j.ejpe.2018.07.003
1110-0621/© 2018 Egyptian Petroleum Research Institute. Production and hosting by Elsevier B.V.

1. Introduction

Solid waste management issue is the biggest challenge to the authorities of both small and large cities' in developing countries. This is mainly due to the increasing generation of such solid waste and the burden posed on the municipal budget. In addition to the high costs, the solid waste management is associated lack of understanding over different factors that affect the entire handling system. An analysis of literature and reported related to waste management in developing countries, showed that few articles supplied quantitative information. The objective of the mentioned studies was to determine the stakeholders' action/behavior that have a role in the solid waste management and to analyze different factors that affect the system. The studies carried out in 4 continents, in 22 developing countries and on more than thirty urban areas. A combination of variable methods that were used in this study was mentioned in details in order to encourage the stakeholders and to assess the factors influencing the performance of the solid waste management in the studied cities [1].

Population increase, rapid urbanization, booming economy, and the rise in the standard of living in developing countries have greatly accelerated the rate, amount and quality of the municipal solid waste generation [2].

2. Sources, composition and characterization of the solid waste

Municipal solid waste (MSW) is one of the important challenges to the environment. Municipalities; generally; are responsible for the waste management. They have to provide an effective and efficient system to the inhabitants. Nevertheless, they are; often; facing with many problems beyond the ability of the municipal authority to handle the MSW [3]. This is essentially due to financial resources, lack of organization and complexity [4].

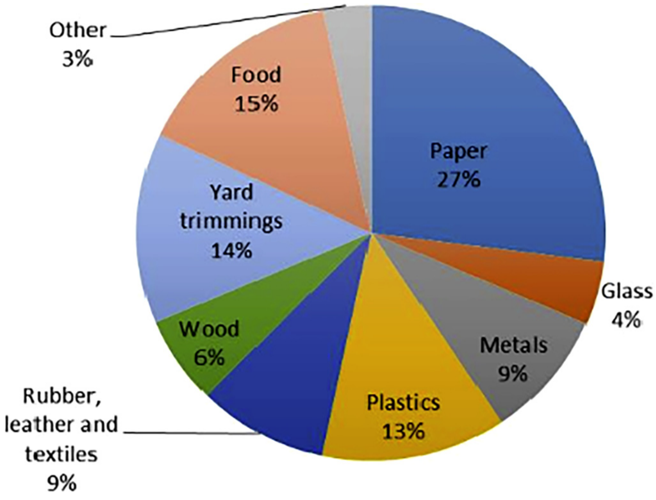

Fig. 1. Composition and classification (by material) of MSW generated by the United States in 2013 [7].

The composition of MSW varies significantly from one municipality to another and from country to country significantly. Such variation depends mainly on the life style, economic situation, waste management regulations and industrial structure. The quantity and the composition of the municipal solid waste are critical for the determination of the appropriate handling and management of these wastes. Such information is essential and useful to put up the solid waste to energy conversion facility within the municipality. Based on the calorific value and the elemental composition of MSW the engineers and scientists can decide upon its utility as a fuel. Meanwhile, such information will help in predicting the makeup of gaseous emissions. Thereafter, this MSW is subjected to the energy conversion technologies including gasification, incineration etc. However, the possible hazardous substances occurring in the ash should be considered carefully [5]. In this respect, the composition of the waste will provide valuable information on the utility of the material for either composting or for biogas production as fuel via biological conversion [6].

Meanwhile, the time has a great effect on the composition of MSW. Biodegradation of such MSW according to the time is an important factor that governs the amount of recyclable material particularly the organic contents. The EPA estimated the amount of MSW generation in the United States with 254 million tons in 2013 [7]. The composition and classification by material of such MSW is given in Fig. 1.

Household or municipal wastes are usually generated from variable sources where different human activities are encountered. Several studies reported that the municipal solid waste that are generated from the developing countries are mainly from households (55–80%), followed by market or commercial areas (10–30%). The later consists of variable quantities generated from industries, streets, institutions and many others [8]. Generally, solid waste from such sources is highly; heterogeneous in nature. Thus, they have variable physical and chemical characteristics depending on their original sources. Their composition are yard waste, food waste, plastics, wood, metals, papers, rubbers, leather, batteries, inert materials, textiles, paint containers, demolishing and construction materials as well as many others that would be difficult to classify. The heterogeneity of such generated solid waste is the major setback in sorting and its utilization as material. Therefore, there is a proper need for fractionation and sorting of these wastes before any meaningful treatment process. Sorting and separating of such wastes are one of the most important and traditional methods as essential steps in solid waste management to provide data on the quality of the separated fractions for any potential utilization. Nevertheless, the success of any designed for solid waste segregation depends mainly on the public awareness and the active participation of such waste generators in the different communities (i.e., how they follow the fundamental and principles of waste sorting and separation) [9].

Solid waste generation (SWG) is a problematic and is an issue of concern everywhere in the world, particularly in all urban centers. Such SWG is considered one of the most challenging issues faced by most developing countries that suffer from sever environmental pollution problems caused by the large quantities of SWG [10]. Increased generation of solid waste in urban cities affected dramatically on the sanitary related problems and the basic services such as sanitation facilities, water supply, waste management, and transport infrastructure [11].

Several studies showed that collection, storage, transportation and final disposal of solid wastes are a major problem in urban cities and areas [12]. Cities in East and North Africa as well as most developing countries are also facing the same serious problems related to SWG. The main reason of these problems is attributed to the poor economy of these areas which accounts for the low achievement in solid waste management [12]. Most of these developing countries fail the in solid waste management and issue due to the limited available resources and the competing priorities over their resources. Thus, the SWG is; indeed; one of the serious and major problems faced by many cities in the world.

Meanwhile, the SWG and composition influenced by other socioeconomic factors including the average family size, number of room(s), monthly income, and employment status [13]. It was also reported that there is a direct relation between the solid waste composition and the social activities in the community [14]. In addition, other factors including change in the source-sorting behavior and consumption of goods are among other factors affecting the composition of the solid waste and the quantity in households [15].

Socio-cultural, economic, legal, political and environmental factors as well as the available resources are the main issues that affect the MSW management in all countries [10]. That is why adoption of any new technology for MSW management and SWG should take into account the effect and the influence on the socio-cultural and the economy of the community.

As the result of the changes in consumption behaviors of people as well as the rapid advances of technology, amounts and the composition of MSW have been also changed. In a study carried out by the European Environmental Agency [16] to study the per capita annual MSW produced by 32 European countries during 2001–2010, they found that this waste increased in 21 countries, and was decreased in 11 countries. The study also studied the amount of wastes of 26 countries between 2001 and 2008; they found that these amounts decreased in 6 countries [16]. Thus, the amounts and characteristics of the wastes varied from country to another country, as well as from region to region even within the same city according the mentioned factors including the usage habits of people [17].

2.1. Food solid waste

Sustainable and important source for certain industrially chemicals can be obtained from the large amounts of the generated wastes in the world. Food residues and waste such as kitchen refuse, garbage and swill [18] are described; generally; the by product and as solid wastes of food. Such wastes are produced from the processing, cooking, distribution, production, and consumption of food. However, food wastes and their definition are greatly varied from cities and countries to other cities and countries. Food wastes; in the European Union; are defined as "raw or cooked of any food substances that are discarded, or intended or required to be discarded". On other hand, the (EPA) U.S. Environmental Protection Agency defines the food wastes as "Un-eaten foods and food preparation wastes from residences and commercial establishments including restaurants, grocery stores, and produce stands, institutional cafeterias and kitchens, as well as industrial sources such as employee lunchrooms." Furthermore, "Food loss" and "Food waste", in the United Nations, are recognized differently. The term "Food losses" refers to the decrease in food quality and/or quantity. On the other hand, the term "food waste" refers to the food losses due to retailers' and /or consumers' behavior [19]. However, food wastes include the uncooked raw materials, wasted foodstuffs, and also the edible materials from groceries or the wet market.

2.2. Wastes as a source of income

Characterizations of the solid wastes were extensively studies [20–25]. In addition, the socio-economic utilization of solid wastes was also studies to investigate the possible income from these wastes [26,27]. In this respect, Yay [28] analyzed and studied the management issue of the wastes in the Sakarya province, Turkey. In his study, Yay [28] collected one ton samples of the solid waste during a period of one year, he suggested the most possible and suitable management of these wastes. Further investigation was carried out focusing on the characterization of the collected solid wastes during four different seasons in a period of one year. These wastes were represented three different groups according to the socio-economic style of living in Lahore city, Pakistan. He found great differences in composition of the collected solid waste based on socio-economic conditions as well as the level of income [29]. Furthermore, the characterization of the solid wastes was studied by Banar and Ozkan [20] in the province of Eskişehir, Turkey. They classified their study on the different income categories. Their classification divided the groups into low, middle, and high income classes. Thus, they conducted the components of the solid waste and their proportions based on income of each group. In further characterization study based on the levels of income variations namely low, middle, and high. Their suggestions and recommendations were made in respect to waste management [30]. On the other hand, Gómez et al. [31] considered the seasonal variations to classify the characteristics of the solid wastes. They focused on three different socio-economic groups in their study.

To select and plan for the most suitable system of transportation, storage, and disposal of solid waste, the characterization and composition investigation play a significant role in such waste management. Meanwhile, characterization is important to determine any possible environmental impacts including nature and society [32]. The average plant nutrient element contents in most MSW is between 0.5 and 0.7 for nitrogen, 0.5 and 0.8 for phosphorus and 0.5 and 0.8% for potassium. The calorific value ranges between 200 and 3000 Btu/lb [32].

3. Disposal of solid waste

It has been reported that improper bin collection practices, collection, transfer and/or transport systems have great effect on the characteristics of the solid wastes. Besides, the poor route of planning, lack of information concerning the collection schedule [33], number of vehicles for solid waste collection and poor roads [34] and insufficient infrastructure [35] can also effect of the characteristics' of the solid wastes. The effective ways and affordable waste collection services were studied and reported by Sharholy et al. [36]. To organize the informal sector and promoting micro-enterprises. Knowledge of treatment by authorities is one of the important factors affecting the handling of solid waste [37]. Factors influence household waste disposal were analyzed by Tadesse et al.

[38]. Their results indicated that the supply of waste facilities significantly affects the choice of waste disposal. They reported that the inadequate supply of waste containers as well as the longer distance of transporting these containers increases the possibility of dumping such wastes in open areas and roadsides along the trip. Pokhrel and Viraraghavan [39] mentioned that insufficient financial resources, absence of legislation, well equipped, and engineered landfills all contribute to the limitation of solid waste safe disposal.

3.1. Plastics waste disposal

The plastics waste disposal is a major global environmental problem. Amount of 50 million tons of post-consumer plastic waste are generated annually by Europe, USA and Japan. Disposal of these plastic wastes in landfill is considered a non-sustainable from the environmental point of view. Moreover, landfill sites and their capacity are decreasing rapidly. On the other hand, legislation is stringent worldwide. USA legislation and several European directives are concern with plastic wastes disposal and management [40].

As plastics are essentially hydrocarbons, they possess a calorific values ranged between 30 and 40 MJ/kg. Thus, they can be burned or incinerated in the municipal or other dedicated wastes with power and heat generation. They can also serve as an additional fuel to replace the fossil fuels in several production processes such as blast furnaces and cement kilns. A complete destruction of these plastics wastes can be achieved by such thermal applications. This application of burning plastic waste; thus; is replacing fossil fuels. However, this leads to additional advanced pollution control measures [41]. Nevertheless, greenhouse gas emissions can be reduced by an efficient waste management [42]. Several reports are published concerning the environmental impact of incineration and/or landfill practice [43–46]. These studies emphasized that plastics and other non-biodegradable materials will persist in the landfill, whereas the biological solids (bio-solids) will be transformed anaerobically into landfill biogas, as energy resource. Therefore, the impact of incinerating the plastics and other non-biodegradable materials is hazardous due to the release of more greenhouse gases than landfill.

3.2. Disposal of municipal solid waste

One of the major environmental problems is the collection, management and disposal of the MSW in the urban areas. Lack of MSW management and disposal is leading to significant environmental problems. This includes soil, air water, and aesthetic pollution. Such environmental problems are associated with human health disorder, due to the increase in greenhouse gas emissions [47].

The waste streams originating from industrial sources are different than the hazardous substances in household waste [48–50]. They are not strictly controlled under hazardous waste regulations such as the European Hazardous Waste Directive 91/689/EEC and the U.S. Resource Conservation and Recovery Act 1976 (RCRA) (US Code, 1976) [51]. The household hazardous wastes (HHW) are disposed of in landfills along with general household waste (HW). The amounts, quality and significance of such disposal are poorly understood. It is, generally, assumed that the amount of HHW's are small, thus, risks of disposal are negligible. Nevertheless, the separate disposal of industrial, MSW, and other wastes raises the importance of the toxic and hazardous element contained in such wastes [52]. There are great concerns about the presence of several chemicals in the household products [53]. The consequences and the impact to the environment resulted from the disposal of HHW are also of concern. Thus the disposal of such HHW to landfill should, therefore cope with the current legislation in order to decrease the risk to the environment [52].

Globally, about 71% of MSW's are disposed of in landfills [54]. MSW contains, mostly, hazardous substances including some batteries, paints, mercury-containing waste, pharmaceuticals, vehicle maintenance products, and many other products [55]. On the other hands, more than 53% of the landfilled wastes consist of hard board paper, yard waste, papers and food that are biodegradable by the anaerobic bacteria [56]. This makes the land filling as the primary method of disposing waste in the Europe and USA.

Most of MSW's as well as many other solid wastes are disposed of in landfills. Thus, a basic understanding of the landfill design is helpful. For example, in the USA, the design and operation of landfills is regulated by the New Source Performance Standards of the Clean Air Act, and Subtitle D of the Resource Conservation and Recovery Act, as well as the other related state regulations. Therefore, landfills have evolved from just open dumps to highly engineered facilities and site that are designed to contain waste. They are separated from the environment, capture polluted water that contacts the waste (i.e. leachate), and control gas migration. A landfill site is designed as typically excavated and lined with a system that includes layers to protect groundwater by minimizing the migration of leachate to the ground layers and to collect such leachate for treatment. A cross section of typical landfill design is given in Fig. 2.

3.3. Problems of solid waste disposal within rural communities in developing countries

Disposal of garbage as solid wastes is a stengent and widespread problem in both urban and rural areas in several developing countries. Several Canals and drains as open places are widely used to dump varieties of garbage as a source of domestic organic and inorganic waste. Due to the absence of continuous garbage-collection systems, convenient landfills, open canals and drains are being blocked by dumping huge amounts of solid and garbage wastes. Thus, they are no longer in function. These garbage wastes are mostly plastic and papers and little toxic matrials. However, such toxic matrials represent hazard impact to the environment due to the breakdown of their degradable constituents, a matter that adds significant loads of the BOD to the local eco-system.

Many people and most organizations did not arrange for on-site treatment and/or safe disposal of the solid wastes to cope with the environmental preservation measures. Disposal of garbage solid waste and of untreated effluent into the nearby drains by people is; thus; irresponsible and are not aware with the sequences of their health hazard. There are no what is called financial incentives to stop them from such prctice and to encourage them to alter their habits. Individual see that the way they dispose their wastes is effective and cheap. In fact, it is serious disaster for the the surrounding communities and to the country. The fact is small volumes of effluent induces pollution to very large volume of water bodies. Meanwhile, laws are not effective to prevent the environment from such hazardous practice unless better sollution could be achieved.

4. Management and recycling of solid waste

In terms of pricing for solid waste disposal, Scheinberg et al., reported that there are indications that high rates of recovery for recycling are associated with tipping fees at the site of disposal [57]. High disposal pricing has the positive effect on recovering the generated solid waste. This goes to the beneficial reuse or the value chains of solid waste. Gonzalez-Torre and Adenso-Diaz mentioned that social influences, altruistic and regulatory factors are

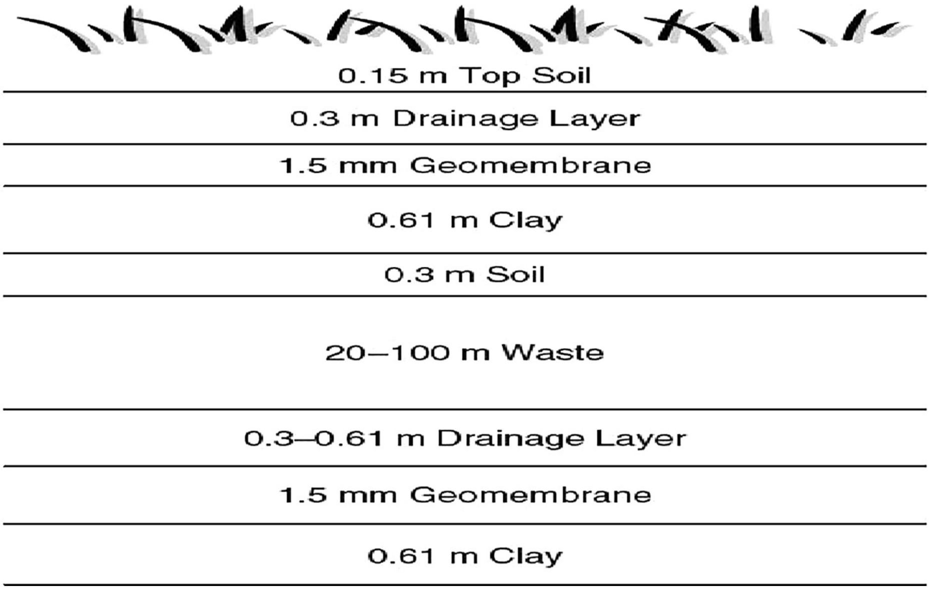

Fig. 2. Typical cross-section of a landfill receiving MSW [56].

important reasons why certain communities can develop strong recycling habits [58]. The author also reported that people who frequently go to dispose their general refuse in the bins are more likely to recycle certain products at home. In most cases, as the distance to the recycling bins decreases, the number of fractions that people separate, sort and collect their solid waste at home increases. Minghua et al. added that in order to increase the recycling rates, the local government must encourage the markets for the recycled materials and should increase the professionals in the recycling companies [2]. Further important factors were mentioned by other scholars including a financial support for different recycling projects [59], to support the infrastructure of the recycling companies in their country [34]. Other investigators suggested to drop-off and buy back centers [60]. Sharholy et al. [36] suggested organizing informal sector for solid waste recycling [36].

Indeed, MSW collection and disposal is a one of the major problem of urban environment in most countries worldwide today. MSW management solutions must be financially sustainable, technically feasible, socially and legally acceptable as well as environmentally friendly. European policy, presently, is pushing to adapt several rational managements towards the natural resources. Today, waste valorization is a promising technological perspective. It becomes a process that is possible through sorting the MSW at the source, and to combine with material recycling as well as waste-to-energy generation methods. However, technologies like disposal or mechanical sorting of the MSW in landfills do not improve the MSW management efficiently. Therefore, landfills must be the ultimate disposal site of the MSW. Nevertheless, construction of conventional landfills for MSW disposal is still going on in many countries. It was reported by Hadjibiros et al. [61] that site selection of the landfill is extremely important due to the lack of public acceptance that result several social problems [61].

For sustainable management of solid waste, effective planning and development strategies about the quantity and categories of such wastes are of great importance. Thus the most important processes are quantification and characterization of all the sustainable solid waste management systems according to Senzige, et al. [62]. At a particular place, studying the composition and the categories of solid waste is important for integrating technologies including recycling and resource recovery in the concerned solid waste management systems. The information also can certainly assist in infrastructure, policy development, and planning for any sizing decisions concerning the integrated solid waste management program [63].

For preventing any serious environmental health risks and treatment of these wastes management is strongly required [64]. The most used and cheapest disposal of solid waste is the landfills as waste management techniques [65]. From the beginning of civilization people have produced solid waste. During these earliest times, solid wastes were disposed of in large open land space areas. At that time the population density was low. On the contrary, developing living standards, increasing population, and rapid urbanization, todays have created huge amounts of solid waste in all countries worldwide [66]. MSW are originated from different activities carried out in homes, in public and private service as well as buildings, and commercial services. They all form an important portion of the solid waste now a day's [64].

Waste management, in fact, addresses the use of multidisciplinary approaches ranging from engineering, humanities, sociology and biology [67]. The level of development of a country reflects the impact on the management of solid waste and the selection of such management [68]. Riber et al. [69] mentioned that many developed countries employ various methods for waste management for producing renewable energy and other new products including compost [69]. These countries invest in waste recycling for the benefit of agriculture activities [70]. Choice of solid waste management depends on the decisions taken by city leaders as well as the structures related to the nature, quantity and quality of local waste produced [71]. Household waste is recognized as any waste produced from a domestic source at home. It represents, usually, more than two-thirds of MSW stream. In this respect, all potential hazard items must be identified and assessed properly to achieve the maximum environmental protection against the hazards and risks associated with open dumping [65]. Increasing the amount of solid waste induces various problems in collection, transportation, and disposal. It complicates the management of this solid waste. Indeed, the MSW has great economic potential and revenue [72]. However, the efficiency of MSW management effects on the potential economic value of this waste [73].

A good knowledge of the solid wastes characterization before disposal is important for the management of MSW. During the management of solid wastes some problems could be arisen due to their possible heterogeneous structure. The physical features of solid wastes are important for selecting the method of collection, transportation, recoverable matter, and energy transformation as well as selecting and designing of the proper disposal methods [74]. Thus, physical features of MSW including composition, calorific value (heating), and moisture content (MC) should be well known to select the suitable methods of management. The moisture of solid wastes ranged from 5% to 40% with an average of 20%. This very wide range of the MC depends on the socio-economic structure and the regional characteristics of the solid waste [75]. Nevertheless, the MC may reach up to 55%–70% depending the on climate conditions, and solid waste composition [76]. It is important to mention that the calorific value of solid waste is highly depending on the MC. It is also a significant parameter for determining the design procedures of combustion for the recovery of solid wastes. It has been estimated by UNEP [77] that solid waste management contributes for the greenhouse gases (GHGs) emission between 3 and 5%. This is mainly due to the emission of CH_4, CO_2, and N_2O that escapes from the open dumps. Additional gas emissions of CO_2 are from the upstream processes such as transportation and waste collection [77]. However, management of waste in an adequate way can certainly reduce or save GHGs emissions via different ways including: energy production, application of compost to soils as fertilizers, storing carbon in landfills, and by avoiding the primary materials through material recovery from waste. It was reported by UNEP [77] that the internationally recognized institutions recommended a future waste management focused on the 3R concept (namely: Reduce, Reuse, and Recycle). These 3R are waste prevention, circular economy establishment, cleaner productions, and valorization of the waste by transformation into a source of energy and materials [77]. The inadequate waste management cause alteration the ecosystems including air, water, and soil pollution, thus it represents a real threatening to human health. The impact of dumping and incineration of MSW on the public health has not been fully studied. Rushton [78] mentioned that some studies gave evidence that local population nearby MSW facilities have low weight at birth, congenital anomalies, and few types of cancers. However, the impacts on this local population seem to vary depending on the studied population. Clarification of this approach concerning the epidemiologic surveys should receive more attention particularly the doubt with human diseases [79]. Problems related the inadequate waste treatment is a serious problem mostly in the developing Countries, due to the limited financial resources. Most of these Countries dump their MSW without proper control. This results in air, soil, and water pollution, consequently. Waste management, thus, represents one of the main issues that have to be faced by mankind nowadays. However, waste should not only be regarded as a source of materials recovery (metals, glass, plastics, and fibers) and energy, but also because of oil saving and as a tool for environmental protection. If we consider the global energy that could be produced only from the agriculture organic waste including crop residues, it is estimated to be around 50 billion tons of oil equivalent [77]. According to the UNEP [77], an adequate separation between organic and non-organic waste is necessary as prerequisite for an effective energy generation. In fact, the organic residues are responsible for the compromising of the thermal technology effectiveness with respect to the produced energy as well as the GHGs emissions. The manner in which this waste is handled is given in Fig. 3.

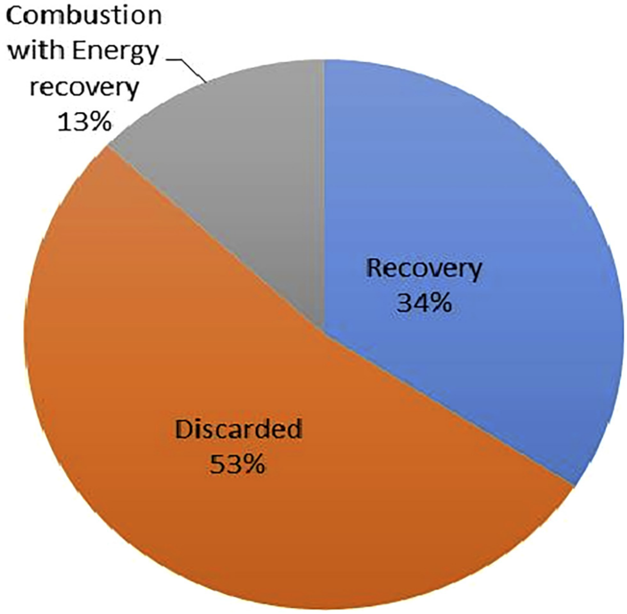

Fig. 3. Management of MSW [7].

5. Valorization of solid waste

Increasingly tighter regulations in terms of organic solid waste, as well as increasing the demand for renewable chemicals and fuels, recently, are pushing the industrial manufacturers and the environmentalists toward higher sustainability to improve cost-effectiveness and meet customers' demand. During the past few years, valorization of food organic waste is one of the important current research areas. It has attracted a great deal of attention as a potential alternative to the conventional solid waste disposal of a wide range of residues in landfill sites. In addition, the increasing development of environmental strategies to process such solid waste is an interesting area of increasing importance in our current society. The conventional landfill, incineration and composting ways of handling solid wastes are common as mature technologies for waste disposal. Nevertheless, they are not satisfactory to treating organic waste. The disadvantages are: high energy consumption, generation of toxic methane gas and bad odor, as well as slow reaction kinetics. Research efforts, in fact, have also been directed to the novel technologies towards the decomposition of organic waste. But, no valuable product is generated from such decomposition process. The recent research has focused on producing energy from the food waste instead of disposing and decomposing (e.g., bioethanol and biodiesel production). Meanwhile, useful organic chemicals can be generated from organic waste via bio-refinery or white biotechnology (e.g., bio plastics and/or succinic) as well as developing sustainable green production strategies [80].

Waste valorization concerns with the process of converting waste materials into more useful products including fuels, materials, and chemicals [81]. Such approach is mostly related to waste management for long time. But this concept has been brought back to our society with renewed interest due to the fast depletion of fuel, natural and primary resources. Recently, the increased waste generation and landfilling worldwide stressed on the need for more sustainable and cost-efficient waste management protocols. Different valorization techniques are currently showing great hope and promise in meeting industrial demands. Among these promising waste valorization strategies is to employ flow chemical technology to process waste into valuable products. Serrano-Ruiz et al. [82] highlighted the advantages of continuous flow valorization processes for biomass and/or food waste that included ease of scale-up, efficient reaction cycles producing more yield, reaction control, and no required catalyst separation. Although flow chemistry is well known to be used in industries for various processing methodologies, it still can be used in biomass solid waste/valorization. The limitation here is caused by the large energy needed to degrade highly stable recalcitrant compounds and biopolymers (e.g., lignin). Most of the time, the deconstruction of such biopolymers, requires extremely high pressure and temperature that can be achieved by microwave heating, which is an additional green valorization technology. These requirements are not so simple to be achieved. Various techniques including microwave irradiation are needed to achieve such prerequisites for any successful transformation of solid waste. Nevertheless, the main challenge for such combination is on the technology and the scale-up itself. Glasnov et al. [83] confirmed that the microwave and flow chemistries are coupled by attaching back-pressure regulators to flow devices. Such approach is certainly revolutionizing industrial valorization because it will synthesize products fast. This can be attributed to the microwave heating on one continuous run (flow process). This approach is possible, nevertheless, the main challenge of transferring the temperature from microwave to flow remains to be solved. The continuous building up of temperature gradient inside the instrument, however, could lead to various instrumental disorder or inefficiency [83].

Further valorization strategy is related to employing pyrolysis in the synthesis of energy or fuels. This strategy involves heating of the biomass at high temperatures in the absence of air to produce the required decomposed products [84]. Although pyrolysis of solid materials is an old process for char generation, it has recently been employed to produce useful smaller molecules from stable biopolymers. This process has been employed extensively for the production of Bio-Oil, which is a liquid, of relatively low viscosity. It is a complex mixture of short-chain ketones, aldehydes, and carboxylic acids. It was reported by Heo et al. [85] that variable conditions for the fast pyrolysis of waste furniture sawdust were investigated. It was found that the yields of Bio-Oil do not necessarily increase with temperature. By using a fluidized bed reactor, the optimized pyrolysis temperature was set at 450 °C (e.g. 57% Bio-Oil yield). Thus, the Bio-Oil yield is not a linear relationship with temperature. The reason for this nonlinear bio-oil yield/temperature is the possible decomposition of some molecules into gases. This founding was supported by the increase in the amount of gaseous products according to the increase in temperatures. An interesting study was carried out by Cho et al. [86] in which they employed fast pyrolysis under a fluidized bed reactor for the purpose of recovering BTEX compounds (xylenes, benzene, ethylbenzene, and toluene) from mixed plastics. The highest yield of BTEX was obtained at temperature 719 °C. In addition, the pyrolysis of cotton stalks was also reported to produce valuable biofuels [87]. This study reported that the pyrolysis at much higher temperatures increases the collected amounts of H_2 and CO, and decreases the amount of CO_2. Such decrease in CO_2 production may be due to the degradation of the gases at much higher temperatures producing CO and O_2. Presently, synergy between these first proposed technologies namely; microwave and pyrolysis; has been also confirmed to constitute a step forward toward more ecofriendly low temperature pyrolysis protocols for both bio-oil and syngas production [88].

5.1. Valorization of solid waste from olive oil industry

The global olive oil production for 2010 was estimated at 2,881,500 metric tons. The European Union countries are the highest in olive oil production; they produce 78.5% of the total production. The average European Union production is 2,136,000 tons in 2010. Between year 1990 and 2010 the worldwide consumption of olive oil increased around 78%. Different traditional as conventional as well as non-conventional adsorbents processes have been employed for the olive mills wastewater remediation [89–90]. Olive oil industry produces enormous amount of solid and liquid wastes that cause serious environmental problems. The increase in olive oil production represents an increase in olive mill wastes. Consequently, olive oil production is facing severe environmental problems due to lack of effective, feasible and/or cost-effective solutions to olive-mill waste. As a result, stinging need is required to find an effective and feasible way of management for the treatment of olive mill waste materials in order to minimize environmental impact and the associated health risks. The management of olive mills solid and liquid wastes is always challenging. Thus extensive efforts have been made by several researchers to utilize such wastes in different beneficial products [90,91] (Fig. 4).

Therefore, it is, highly desirable to manage these wastes through feasible technologies in eco-friendly way that can minimize their environmental impact and lead to a sustainable use of resources. In this respect Bhatnagar et al., [93] reported an interesting study in which the olive mills solid wastes were used as inexpensive adsorbents for water pollution control. Lately, research has been conducted for developing low-cost adsorbents utilizing eco-friendly naturally occurring and agro industrial waste materials for treatment of wastewater. These materials are abundantly available, renewable, and cheaper [94]. Recently, extensive focus is given to employ the industrial solid wastes or the by-product. Sometimes, these wastes pose serious disposal problems. Thus, it provides a double-fold advantage in terms of environmental pollution. Firstly, the volume of olive mill solid waste materials could partly be reduced. Secondly, the employed low-cost adsorbents can treat industrial wastewaters at a reasonable and feasible cost. It has been estimated that the wastes from olive industry could be converted into low-cost adsorbents at the cost of < \$50/ton against \$4500/ton for granular-activated carbon [95]. Researchers have used different olive mill solid wastes by applying various physical and chemical treatment methods to produce efficient adsorbents for the removal of various aquatic pollutants. The nature of the precursor, the processing conditions, and the type of activation (chemical or physical) are important to define the adsorptive properties of the developed adsorbents from olive wastes. In case of chemical activation, concentration of the dehydrating agent, pyrolysis temperature and impregnation ratio govern the properties of the resulting adsorbent. Different olive mill solid wastes have been characterized by different analytical techniques. Fourier transform infrared spectroscopy (FTIR) studies revealed that olive wastes contain various functional groups including methoxy, hydroxyl, carboxylic, and phenolic groups that are potentially active in heavy metals removal. This particular composition enables olive solid wastes to bind metallic ions and some other pollutants from wastewater. Such particular composition make them potential bio-sorbent towards water treatment applications.

5.2. Treatment and valorization of organic waste

Traditionally, the most commonly used technologies for the treatment and valorization of the Organic Fraction of Municipal Solid Waste (OFMSW) are the composting and Anaerobic Digestion (AD) (UNEP 2010). These two employed waste treatments varied essentially for the microbial metabolism they use. AD is based essentially on the anaerobic microorganism's metabolism, particularly the methanogenic bacteria. Such anaerobic metabolism produce CH_4 from CO_2 to H_2 (hydrogenotrophs) and/or from CH_3COOH (acetoclastics). An appropriate temperature is requires for the AD digestion. Generally, a temperature between 35 °C and 50–55 °C is required to realize the reactor. However, for the psicotrophic process, temperature between (10–20 °C) is also possible. As a result of this AD, a biogas consists mainly of CH_4 is

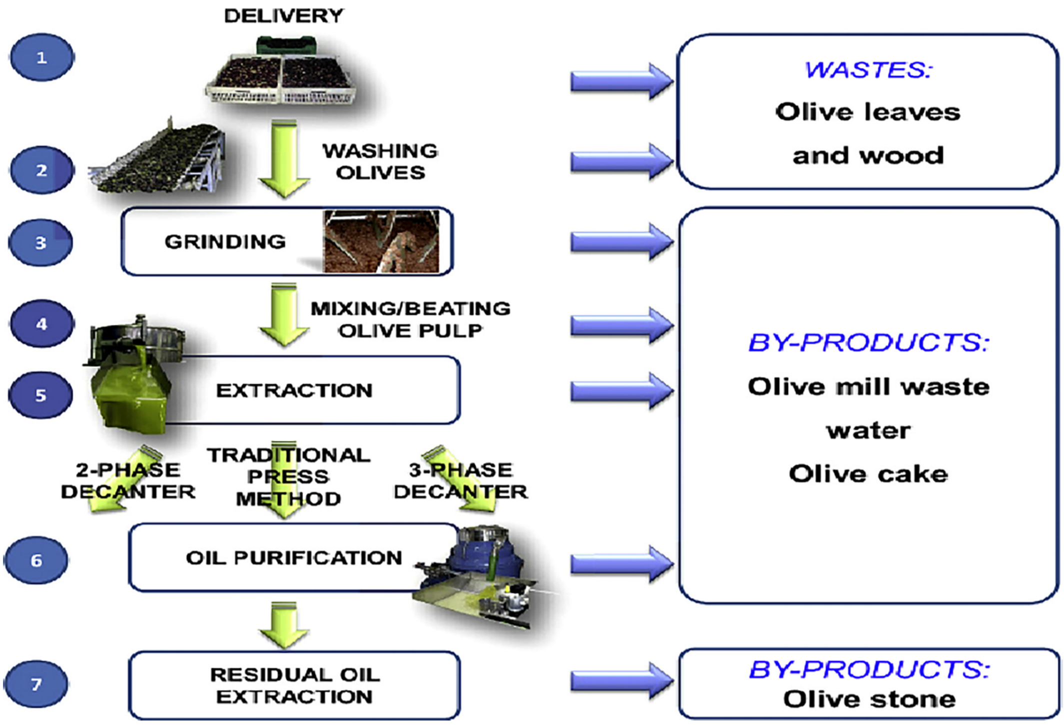

Fig. 4. Solid and liquid wastes and the by-products obtained during olive oil production process (Three-phase extraction method) [92].

produced. Often, the resulting digestant is aerobically stabilized. On the contrary, a successful composting process needs sufficient oxygen to sustain the aerobic microorganisms, thus inhibiting any possible anaerobic bacteria. Small amounts of organic wastes can be easily composted. But, large-scale composting requires mechanical aeration such as energetic imputes that varies between 40 and 70 kW/t of waste according to the technology used [96]. This required energy is normally provided to the composting system. It is worth mentioning that several facilities combine the AD followed by aerobic stabilization to provide the energy needed for the composting process from the self-supplied biogas (methane). It has been estimated that if 25% or more of the municipal organic waste (MOW) is anaerobically digested, the whole wastewater treatment system can be self-energy sufficient [77]. The final "product" of composting system is the stabilized organic matters that can be used as a soil conditioner in agriculture, if they are free from chemical or biological contaminants. Utilization of composted municipal organic wastes in field application can certainly reduce the use of synthetic fertilizer for agriculture purposes (about 20% according to IPCC [97]. Thus, the soil conditioner application has important positive impact on GHGs emission from fertilizers production as well as on N_2O emissions from soil. It also reduces irrigation, tillage, and pesticides [98]. For developing countries, particularly, simplicity and the low cost of composting make small-scale composting an eco-friendly and promising solution. Meanwhile, this approach represents a potentially low cost and effective technology for organic solid waste and wastewater treatment as an important tool for waste management in developing poor countries [99].

5.3. Solid state fermentation for organic waste valorization

The generation of organic solid waste; worldwide; is dramatically increasing each year. As a result, problems related to disposal of these organic solid wastes have become more pronounced in recent years. This is mainly due to the rapid pace of development towards worldwide modernization as changes in style of life. Most of the organic solid wastes are composed of agricultural waste, household food waste, human and animal wastes, etc. They are normally handled as animal feed, incinerated or disposed to landfill sites [100]. Nevertheless, incineration is a costly disposal method and induces air pollution. On the other hand, the disposed organic waste in landfill is normally broken down and decomposed by microorganisms to form leachate that contaminates the groundwater [101]. Furthermore, the degradation of these organic wastes in such conditions produces methane as greenhouse gas, which is 25 times more harmful compared to carbon dioxide [102]. Incorrect solid waste management practices can result in severs public health and environmental problems including offensive odors and diseases [103]. However, organic solid wastes are comprised of materials rich in proteins, minerals, and sugars that could be used in other processes as substrates or raw materials. Since the cultivation and the growth of microorganism requires, mainly, carbon, nutrient, and moisture. Thus, organic waste could be a good candidate to provide the appropriate nutrient and conditions for the development and growth of these microorganisms. On the other hand, organic solid state fermentation (SSF) is regarded as a promising technology for organic waste valorization via the bioconversion of these wastes used as either substrate or inert support [104]. In this respect, microorganisms will play an important role in the degradation of organic wastes into their constituents to convert them into high value-added products. SSF exhibits sustainable characteristics in the bioconversion of organic solid wastes. The SSF proved to be able to give high efficiency in terms of product yields and productivities, low energy consumption, and solving disposal organic waste problems [100,105]. This valuable SSF process is carried out by microorganisms growing on solid and moist substrates that act as nutrient sources that support the microbial growth in the absence or near absence of water [106]. This SSF is not a new technology in the bioprocessing. It has been mainly applied in the Asian region during the ancient times. It is gaining a lot of attention, recently, due to the increasing use of different types of organic wastes as well as the larger production of the added-value products [104]. The potential of SSF was also highlighted through the search for sustainable and green approach to transform traditional chemical processes. Therefore, the bioconversion of solid organic wastes into valuable bio-products can, certainly, substitute the non-renewable materials as well as transforming the chemical processes into cleaner practices. The advantage of SSF is that it is relatively simple as a process which uses available low-cost biomaterials with minimal or no pre-treatment for bioconversion. It also generates less wastewater, beside the capacity for simulating similar micro-environments that is favorable to the growth of microorganisms. Meanwhile, SSF simulates natural microbiological processes including ensiling and composting [107] (Fig. 5).

5.4. Agriculture organic solid waste

It is well known that the agricultural as well as the agro-industrial activities generate a large amount of lingo-cellulosic by-products including fruit peel, straw, stem, stalk, cobs, husk, and bagasse among others. Such wastes are mainly composed of cellulose (35%–50%), lignin (25%–30%), and hemicellulose (25%–30%) [109].Typically, the main constituent of the lingo-cellulosic materials is glucose. The hemicellulose is a heterogeneous polymer that is mainly comprised of five different sugars (namely: L-arabinose, D-glucose, D-galactose, D-xylose, and D-mannose) as well as some organic acids. The lignin is formed by a complex three-dimensional structure of phenyl propane units [100]. Recently, the SSF was successfully applied to produce hydrolytic and lignin lytic enzymes [110]. The lignin per oxidase was successfully produced by using corn cobs as a substrate in SSF [111]. Regardless to the rising price and the considerable shortage of grains as a custom animal feed, it was reported by Graminha et al. [112] that the lignocellulosic materials have a great potential to produce edible animal feedstuff. Nevertheless, the direct application for animal feedstuff is very limited due to the presence of lignin that reduces its digestibility.

Various pre-treatments of straw was implemented by using SSF for cellulose and lignin degradation for the purpose of increasing the digestibility of the feed [113]. It is worth mentioning that, SSF can have a valuable potential to produce enzymes and to improve the digestibility of rich fiber materials including soybean cotyledon [114]. It has been reported that Jatropha seed cake is used for the production of celluloses through SSF without any pre-treatment [115]. Several investigators reported other uses for similar materials including the reinforcement of composite materials that are applied in building materials, furniture, fishnet, etc. [116] and/or as activated carbons [117]. Most of the time, the agricultural organic wastes include livestock manure. It is confirmed that the cow dung contains a high nitrogen content that made it suitable for methane production [118]. On the other side, the production of activated carbon and biochar were favored by utilization of cow dung and chicken manure [119]. Meanwhile, high-quality of bio-fertilizer can be produced by employing liquid amino acid hydrolyzed from animal carcasses as an additive to mature compost of either pig manure or chicken by SSF [120].

5.5. Industrial organic solid waste

All organic by-product from a large variety of industries including fruit and vegetable processing plants, slaughterhouses, poultry processing, sugar industry, the dairy industry, paper and pulp manufacturing, as well as many others are the industrial organic wastes. Most of these organic wastes have the potential to be used as a substrate or support in SSF processes to produce valuable products. For example, sawdust, that is the solid waste and available by-product of the wood industry, is used as a support substrate in SSF to obtain high laccase production by using white rot

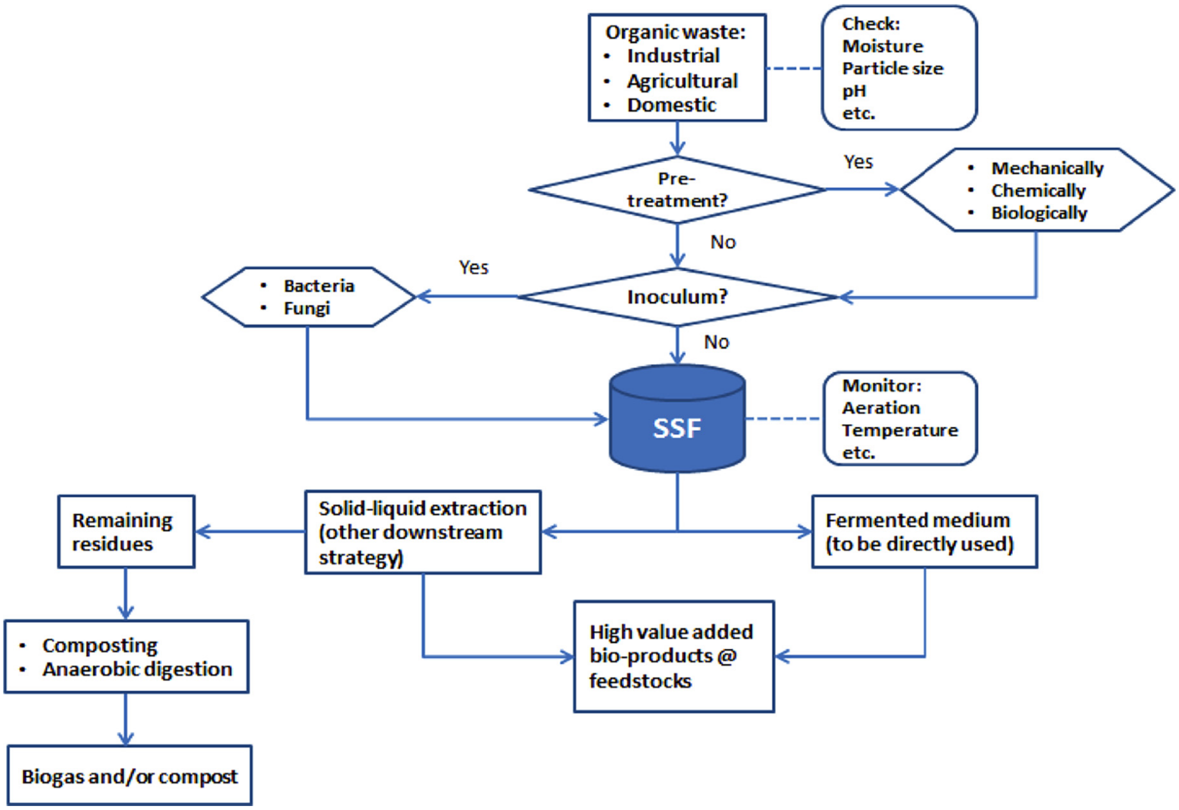

Fig. 5. Valorization flowchart of organic waste to produce valuable bio-products by using solid state fermentation (SSF) [108].

fungi namely Coriolopsis gallica [121]. In addition, the slaughterhouses and the leather industry generate several organic wastes containing protein as well as animal fleshing, skin trimming, hair wastes, chrome shaving, buffing wastes and keratin wastes that are underutilized. It was reported that the animal fleshing is utilized as a substrate in SSF for protease production [122]. The mixture of the slaughterhouses hair wastes mixed with aerobic activated sludge or anaerobically digested sludge showed a high yield of protease production [108]. Meanwhile, the by-products of the sugar industry such as sugarcane bagasse and molasses was reported for the production of invertase via SSF [123]. Besides, molasses was selected as a low-cost substrate to replace an expensive feedstock (cane sugar) to produce ethanol [124]. In addition, the waste of tapioca industry that contains considerable organic matter associated with a strong odor which could cause environmental pollution was successfully converted into poly-3-hydroxybutyrate (PHB) via SSF. Thus an alternative industrial process and significant reduction in the total production cost could be achieved [125]. This proved that the food processing industries, usually, generate several by-products that are able to be used in SSF for producing several valuable bio-products [126]. It has been widely reported that the vegetable and fruits waste can be used for production of organic acid and vital enzymes [127]. Vegetable wastes show a great potential for energy bioconversion due to its high and easily degradable organic content, particularly in the bio-fuel production [128]. It have been reported that crustacean by-products, that are generated in industrial seafood processing, can be used in the production of chitinase and chitosanase with a wide range of applications and implementation in biomedical, food and agrochemical sectors [129]. Meanwhile, fish processing wastes are favorable because these wastes are easy to obtain at low-cost and provide appropriate SSF conditions for microorganism cultivation. Due to rich contents in lipids and proteins, such fish processing wastes, have been found suitable to produce esterase [130]. The latter is a product with a versatile industrial application in organic chemical processing, in detergent formulations, in the surfactant and oleo chemical industry [130].

5.6. Municipal/domestic food solid waste

Several developing countries treat their domestic wastewater inadequately due to the high financial cost [131,132]. In addition, most countries worldwide are facing a serious challenge to manage domestic food waste. It is wet, put in random way, and sometimes mixed with impurities of inorganic waste and metals. Primarily, the composition of such domestic food waste is very complex because it includes papers, water, oil, as well as spoiled and leftover foods from kitchen wastes and markets. All these waste substances are chemically comprised of fats, cellulose, starch, lipids, protein, and other organic matter. The moisture and salt contents lead to a rapid decomposition of the organic contents in the wastes thus produce unpleasant odors. This condition can attract bugs, and flies which are vectors for several diseases. Apart from being perishable, these municipal solid wastes including household kitchen waste as well as the domestic food waste from restaurants and markets consist of high lignocellulosic materials that could be decomposed and exploited to produce valuable bio-products. These domestic food wastes including waste savory, bread, waste cakes, fruits, vegetables, onion and potato peel wastes and cafeteria waste, have been proved as being a suitable substrate for glucoamylase enzymes production by Aspergillus awamori via SSF technology [133]. Domestic bread wastes have been used to produce amylase [134]. Principally, MSW and kitchen waste residues composed mainly of onion peel, potato peel, carrot peel, cauliflower leaves, orange peel, banana stalks and pea pods all together were used to produce cellulose by SSF [118]. Recently, the cultivation of selected industrial yeast strains by using orange peel as a substrate resulted in a high yield of aroma esters [135]. Several studies reported the utilization of household food wastes with high dry content to produce high yields of ethanol via SSF [136]. Similarly, mixed food wastes collected from restaurants and inoculated with fungal inoculum can produce glucoamylase-rich media and protease-rich media by SSF. These media are suitable to be used as a feedstock to produce succinic acid. The later has a wide range of applications such as medicine production, plastics, and laundry detergents [137]. In Nigeria, for example, cocoyam peel is a common household kitchen waste which presents a capability to become a very useful substrate for oxy-tetracyclines, which are an important antibiotic to treat many infection diseases [138]. It is important to mention that, the complex composition of food wastes makes them very suitable for microbial growth as potential media to produce Bacillus thuringiensis (Bt) bio-pesticide through SSF [139].

5.7. Valorization of organic solid waste by employing the black soldier fly, Hermetia illucens in developing countries

In low and middle-income countries organic solid waste management awareness has gradually increased, recently. This resulted in improving collection coverage and reduced dumpsites and landfills of waste management. Thus, recycling and valorization of organic solid waste grew more worldwide attention. Nevertheless, organic contents of the municipal organic waste are still received less attention than other waste products, such as paper, metal, or glass. Often, such organic contents are excluded from this value added chain. It ends up on streets or accumulates on dumpsites, despite its energy content. There, it attracts vector diseases and produces on site greenhouse gases. Treatment technology of such organic waste, using larvae of the black soldier fly, *Hermetia illucens*, is an important way as feasible and sustainable treatment option.

The important solution, presently, is the valorization of such organic waste through this insect: *Hermetia illucens*. It is also known as the black soldier fly. The larvae of the fly are voracious organisms that feed on the organic matter of the wastes via decomposition, excrement, dead animals, etc. Its life cycle is relatively short period (Fig. 6); in which the larva, once fed, migrates to a dry environment. After 14 days an adult fly emerges. In the stage of chrysalis, the larvae reach their largest size. They are rich in proteins and lipids. In addition to the substantial reduction in organic matters volume (betwen 50 and 95%), the products resulting from this method represents an economically values. Simiarly, the use of animal protein in fish farming (pisciculture) as well as the use of lipids in the production of biofuels are the subject of several investigators [140].

The importance of the feeding activity is that it reduces up to 80% of the biomass of organic waste products. It includes market/kitchen waste, animal manure and even human faeces. The so-called prepupa, which is the last larval stage, consists of ~40% protein and ~30% fat, this makes it a valuable alternative to fishmeal as animal feed. In addition to the yield of prepupae, the black soldier fly treatment process generates a second product; it is the residue or digestate. Thus, larval and bacterial activities not only reduce the dry mass but also reduce several nutrient contents including nitrogen and/or phosphorus. For example, in pig manure, 80.5% of total nitrogen and 75.7% of phosphorus were removed [141]. With cow manure, experiments showed a reduction of nitrogen at 43%, and phosphorous at 67% of the waste transformed into larval biomass [142]. A possible use of such residues is the application in agriculture, similar to compost as fertilizer or subsequent processing in a biogas production. Other fruits and vegetables solid

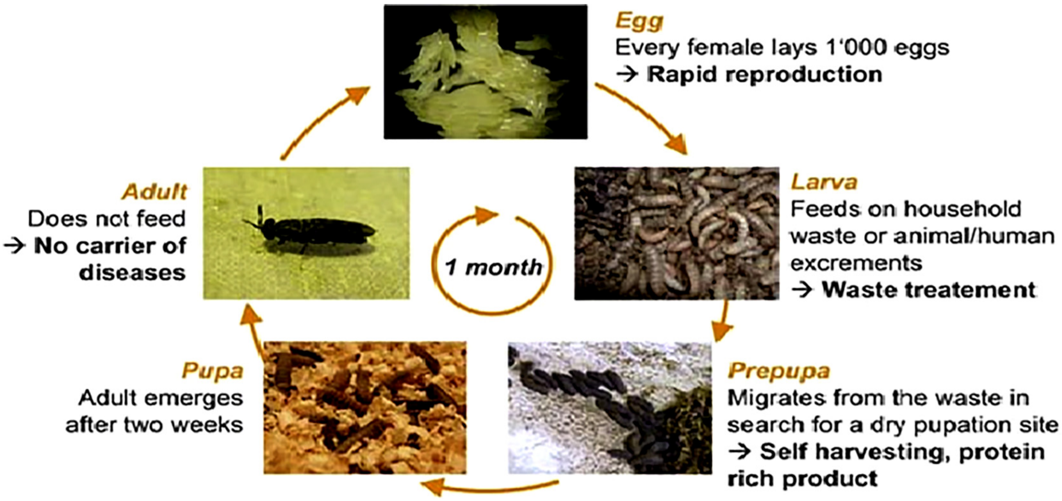

Fig. 6. Schematic diagram illustrate the life cycle of the black soldier fly, *Hermetia illucens*. From [140].

waste are a valuable sources for pharmaceutical and cosmetic industries [143].

5.8. Valorization of organic matter solid waste via composting and anaerobic digestion

Composting process is a controlled degradation of organic matter (OM) in the presence of oxygen. In Florianópolis, there are several small scale companies that produce compost from solid wastes. The advantage of producing compost is the technical simplicity of the process. Nevertheless, the low economic revenue limits the interest of this process. Worm farming is the simple alternative process in which the digestion of the OM inside where the earthworms producing high quality compost and a protein source (worms) [144]. In addition, the AD, is also known as biogas producer or biomethanation. It is the controlled degradation of OM by the anaerobic bacteria in the absence of oxygen [145–147]. Unlike composting process, the AD is a technically complex in which minimal variations in the controlling parameters, such as temperature or pH, can generate a malfunctions of the process (such as odors). However, the produced biogas, as the final resulting from AD, is an important and low cost source of energy. It is considered as eco-friendly source of local energy matrix that reduces dependence on fossil energy sources.

5.9. Valorization of sludge from wastewater treatment plant for biogas production via anaerobic digestion

The waste anaerobic digestion (AD) proved to be an efficient technology for sewage sludge treatment that allows generation of biogas as renewable energy from the same process (Fig. 7). During AD process, the anaerobic microorganisms break down the organic matter contained in the sludge and convert it into biogas as source of energy which can be used for electricity, heat and biofuel production. The produced biogas is a mixture of mainly methane and carbon dioxide. Meanwhile, the sludge is stabilized and its dry matter content is remarkably reduced. The benefits of AD process for sewage sludge treatment are well recognized and the technology is widely established in world wide. Nowadays, a high proportion of biogas produced by the AD plants is from several municipal wastewater treatment sites which are used to cover needed energy for these treatment plants in many countries (Table 1). There is still an enormous potential to exploit this technology in many countries.

Sewage sludge is, generally, produced in wastewater treatment plants (WWTPs) as part of the treatment process to reach cleaner effluent. The obtained sludge contains, normally, the particles removed from the wastewater. Such particles are, usually, rich with nutrients and organic matter, while the treated effluent becomes clean to be released to the nature without any hazardous impact. The fast growing population centers in many countries as well as the expanding industry that are increasingly well served by the WWTPs and facilities. This results in rapid growth of sewage sludge production. In this respect, WWTPs are one of the numerous players influencing developments towards energy sustainability as important consumers and generators of energy. Fig. 8 represents the schematic illustration of a conventional wastewater treatment plant with anaerobic digestion facilities [148].

5.10. Anarobic digestion of sewage sludge for biogas production as affected by heavy metals in the sludge

Sewage water that is mixed with industrial and domestic wastewater may be contaminated with heavy metals and chemicals. It was reported that the presence of heavy metals in the municipal sludge decreased the efficiency of the anaerobic digestion process [147]. These studies indicated that a significant decrease in gas production and the removal of volatile organic matter was recorded. In addition, accumulation of organic acid intermediates was also recorded that is referred to methanogenic bacteria inhibition. Such inhibition is due to the toxicity of heavy metals. It was reported that the toxicity of the heavy metals to the anaerobic digestion of the sludge can be arranged according to the following decreasing order: Hg < Cd < Cr(III) [146]. In this study, accumulation of heavy metals proved to be limited during the pulse feed which could be attributed to the rapid poisoning of the bacteria in the digester. It was, therefore, recommended that the presence of toxic metals in organic solid waste such as Hg, Cd and Cr(III) must be avoided or greatly eliminated in the anaerobic digester. In addition, the industrial wastewater and/or sludge associated with heavy metals should also be avoided in the anaerobic digesters for the biogas production [146].

6. The economic feasibility of solid waste management and valorization

When research is combined with technology, Man can have the power to identify additional innovative ways and be able to make

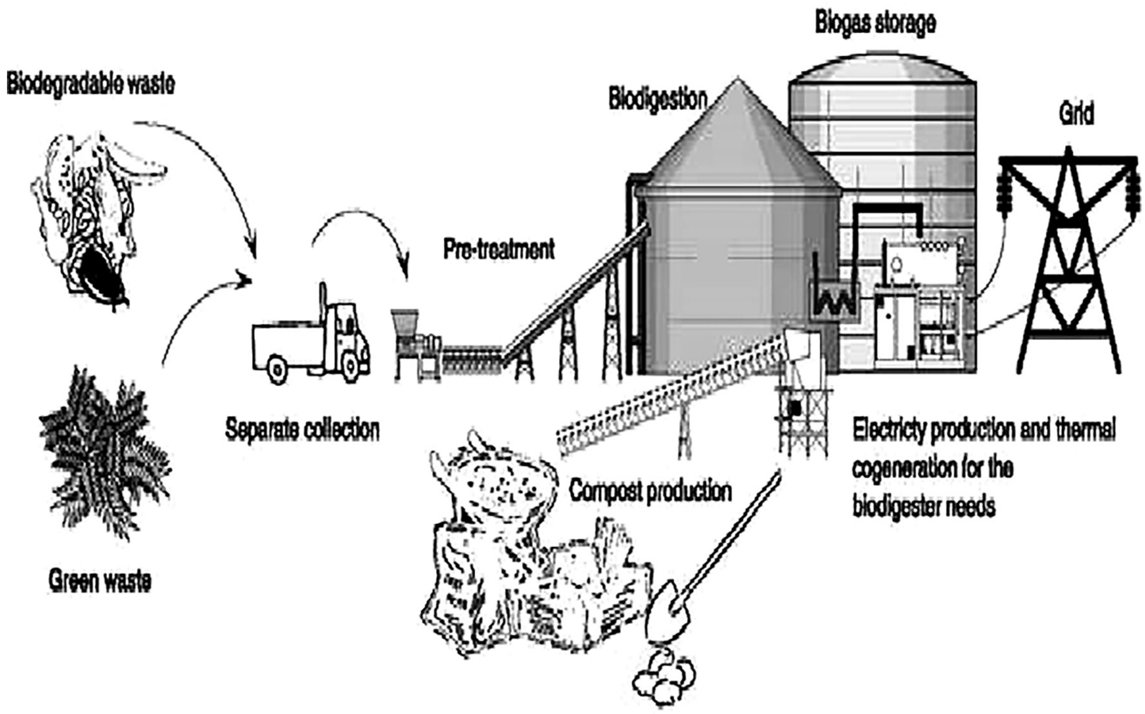

Fig. 7. Valorization complete cycle of solid organic waste by mechanization [145].

Table 1
Biogas production via anaerobic digestion of sewage sludge in WWTPs in Task 37 member countries [149].

Country	Reference Year	Total biogas production (From agriculture residues, industrial wastewater, biowaste, landfills and sewage sludge) GWh/y	Biogas production in WWTPs (Only from sewage sludge) GWh/y	% of total production
Australia		n.a.	n.a.	n.a.
Austria	2013	570[3]	n.a.	n.a.
Brazil	2014	613[3]	42[3]	7%
Denmark	2012	1.218[1]	250[1]	21%
Finland	2013	567[2]	126[2]	22%
France	2012	1273[3]	97[3]	8%
Germany	2014	41.550[2]	3.050[2]	7%
Ireland		n.a.	n.a.	
Norway	2010	500[1]	164[1]	33%
South Korea	2013	2.578[1]	969[1]	38%
Sweden	2013	1.686[1]	672[1]	40%
Switzerland	2012	1.129[1]	550[1]	49%
The Netherlands	2013	3.631[1]	711[1]	20%
United kingdom	2013	6.637[3]	761[3]	11%

n.a. data not available.
[1] Energy generated as gross gas production.
[2] Energy generated as electricity, heat, vehicle fuel or flared (excluding efficiency losses).
[3] Electricity generation only (excluding efficiency losses).

efficient use of the hidden value within the different waste streams generated and expand the life cycle of goods and products. Thus Man can reach multi-side positive effects out of such waste. The valorization of wastes as source of valuable product is associated with resource efficiency and circular economy. The Enhanced Landfill Mining (ELFM) and Enhanced Waste Management (EWM) are the novel concepts because they intend to place land filling of waste in a sustainable context [150]. In the former vision (i.e. ELFM); a landfill is no longer considered the final solution of the solid waste but it is a temporary storage places that should be valorized. ELFM offers a great opportunity to select the most suitable materials to be valorized. These materials can be either as a source of energy (Waste-to-Energy, WtE) or as a product (Waste-to-Product, WtP). This depends on both the type of the waste streams and the state of the technology. The concept of ELFM envisages an important major shift in both the waste management vision as well as the waste management technology. The success of ELFM, therefore, depends not only on technological improvements and breakthroughs, but also on surmounting a multitude of socio-economic barriers (i.e. social acceptance, economic uncertainty, regulations, and feasibility). Thus, the ELFM approach includes the valorization of landfill waste, namely energy (WtE) and materials (WtP) in combination with the ecofriendly approach in preventing CO_2 and other pollutants emissions during the valorization processes.

Despite increasing attention in EU for waste prevention and sustainability, the total MSW generation in the EU has increased from 150 million tons in 1980 to 250 million tons in 2005, to more

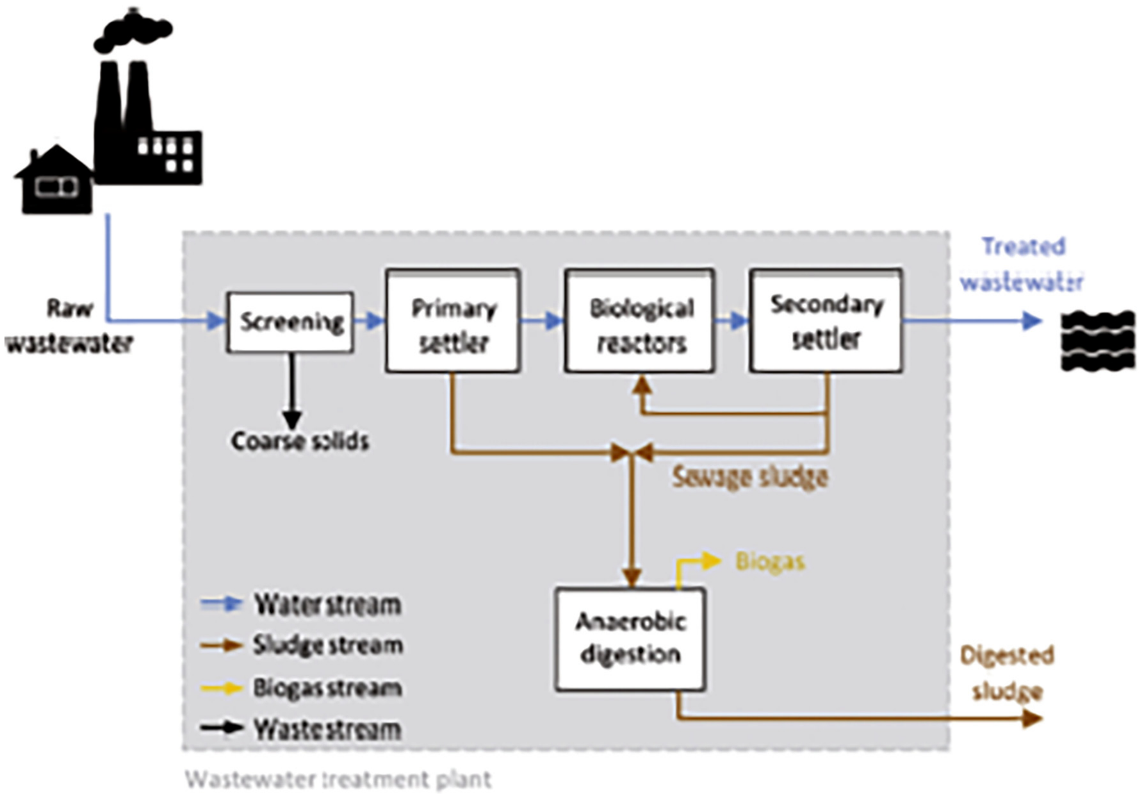

Fig. 8. Schematic illustration of a conventional wastewater treatment plant with anaerobic digestion facilities [148].

than 300 million tons in 2015 and is forecasted to reach 330 tons by 2020 [7]. The MSW in EU is a heterogeneous feedstock; it contains wide varieties of materials in terms of composition, sizes, and shapes. If this MSW is used to produce energy (WtE), this can lead to variable and unstable operating conditions with a fluctuating product quality. The refuse derived fuel (RDF) that are processed form of MSW as organic wastes, are often employed as input to produce energy WtE. Such treatment process usually is associated with reduction in different factors including sorting, screening, and size. In some cases, this process includes drying and/or rough packaging to improve handling and homogeneity of these materials. From the economic and environmental point of view, the main benefits of converting these MSW's to RDF are lower pollutant emissions, a higher heating value, reduced excess air requirement during combustion, more homogeneous physical and chemical compositions, and finally, easier storage, handling and transportation. Managing solid waste and the secondary waste resources is a real complex activity. It requires comprehensive and integrated approaches. A relatively new waste management system approach is the "Integrated sustainable waste management" (ISWM). This ISWM allows municipalities and other similar activities to optimize local waste management and to maximize environmental and valorization benefits at the lowest economical possible cost [151]. The solid state fermentation process has proved to yield a better and higher biomolecules concentrations. It makes further additional downstream processes to be easier than in submerged fermentation (SmF). As a result, SSF minimized the requirements for any additional energy, equipment and water consumption. The cost of substrates represents 30–40% of total production costs. Valorization of the organic solid waste of this substrate in the SSF effectively reduces the operational costs [152]. The several biotechnological processes of SSF are superior in correlation with SmF with respect to the attractive economic feasibility. In a study carried out by Zhuang et al. [153], they compared an economic analysis of cellulose for bioethanol production by SSF and SmF. This study they reported the unit costs for the cellulose production, they found that it is (\$15.67 $\text{kg}\cdot\text{cellulase}^{-1}$) by using SSF and (\$40.36 $\text{kg}\cdot\text{cellulase}^{-1}$) by using SmF, while the price in the market was around \$90 $\text{kg}\cdot\text{cellulase}^{-1}$. In a further study to compare the production cost by the same investigators [152], they found that SSF was lower than SmF with an efficiency of 99.6%. Moreover, it was reported that the economic analysis of hydrolases enzyme cocktails (amylase, cellulase, xylanase, and protease) by using A. awamori onbabassu cake in SSF suggesting that fermented cake or the solid residues generated after enzyme extraction is a byproduct that can be sold as animal feed. This, in turn can compensates the enzyme production costs [154].

6.1. Solid waste management in the developing countries

Because of the demographics changes, consumer behavior, rapid urbanization, and fast growing population municipalities in the developing countries, the decision makers are confronted with serious new challenges in solid waste management. Numerous cities have increased their efforts, over the past few decades, to find sustainable solution in the solid waste management problem. Particular focus was to develop integrated solid waste management strategies, including construction, operation and maintenance of sanitary landfills and the related problem. To cover part of the costs, it was found that valorizing and recycling activities, has turned into a valuable income. It was reported that in Ankara, Turkey, as an example, scavengers collect and sell to middle men about 50% of the recyclables wastes produced by households, commerce and trade that yield a total amount of USD 50,000/day [155]. Furthermore, in Delhi's waste management system at least 150,000 waste pickers divert more than 25% of all waste generated into recyclables. This management system saves the municipal authorities substantial costs [156].

In low and middle income countries, organic waste still continues to cause a lot of problems as a result of no definite solution has yet been identified. A successful development from experimental to full-scale waste treatment systems, offers several advantages by using the larvae of the black soldier fly. Since such systems can be developed, implemented and operated at low cost (including low building, operation and maintenance costs that are independent from power supply), they are more adapted to the developing countries. In addition, creating additional value and generating further income by the sale of harvested prepupae and/or their use in animal husbandry can certainly strengthen the economy revenue of farmers or the small entrepreneurs. Agricultural studies confirmed that the high cost of feed is certainly an important factor for smallholder poultry production in Africa (Malawi, Ghana). Strategies to counteract and overcome the high feed prices may be achieved by switching to other poultry species including waterfowls. The later can be raised with other feed (snails, water hyacinths). Another further option could be to supplement and/or replace the feed with alternative other materials produced locally or by the farmers themselves to ease and reduce the financial burden of the smallholder farmers. Prein and Ahmed [157] stressed on the advantages of the integrated agriculture-aquaculture (IAA) systems which provides very successful examples from Africa (Malawi, Ghana) as well as Asia (Bangladesh, Philippines). In addition, Ahmed and Lorica [158] stressed on the positive effects of small-scale aquaculture on the income of household, employment as well as consumption. It was, therefore, concluded that the use of a black soldier fly CORS system of well design and under feasible operation can meet the requirements of these extensive cultures because the yield in prepupae can be used directly. In low and middle-income countries, the fly can act as an ecological engineer.

The high nutrient elements of dried soldier fly prepupae namely protein and fat content reinforces its high potential value as fly meal in animal feed production. Thus, the aquaculture industry becomes a rapidly growing and very attractive market for dried soldier fly prepupae. Such economic activity grew worldwide by an average of 6.1% between 2002 and 2004. Many low and middle-income countries showed growth rates as high as 11.2% for Chile, 16.5% for Iran, 30.6% for Viet Nam, and 40.1% for Myanmar, and the latest exhibited the highest growth rate [159]. The fish meals and the fish oil became the main food sources for most farmed aquatic species. Presently, the rapid worldwide spread of aquaculture leads to an increase in demand for fishmeal derived from wild fish stocks. It also increased the fishmeal price and induces pressure on the natural fish populations. As a result, alternative animal protein sources, will be highly attractive for farmers currently depending on fishmeal. Therefore, the prepupae of *Hermetia illucens* could be served as this alternative protein source.

7. Conclusions

Solid waste is one of the important challenges to the environment. The inadequate waste management cause alteration the ecosystems including air, water, and soil pollution, thus it represents a real threatening to human health. Some studies gave evidence that local population nearby MSW facilities have low weight at birth, congenital anomalies, and few types of cancers. The increasing generation of solid wastes posed the burden on the high costs of municipal budget. Population increase, rapid urbanization, booming economy, and the rise in the standard of living have greatly accelerated the rate, amount and quality of the municipal solid waste generation. Biodegradation of MSW according to the time is an important factor that governs the amount of recyclable material particularly the organic contents. MSW generated from the developing countries are highly; heterogeneous in nature.

The improper bin collection practices, collection, transfer and/or transport systems have great effect on the characteristics of the solid wastes. The plastics waste disposal is a major global environmental problem. As plastics are essentially hydrocarbons, they possess a calorific values ranged between 30 and 40 MJ/kg. Thus, they can be burned or incinerated in the municipal or other dedicated wastes with power and heat generation.

The most used and cheapest disposal of solid waste is the landfills as waste management techniques. Waste valorization concerns with the process of converting waste materials into more useful products including fuels, materials, and chemicals. It has been estimated that the wastes from olive industry could be converted into low-cost adsorbents at the cost of <$50/ton against $4500/ton for granular-activated carbon. Anaerobic Digestion of Municipal Solid Waste (OFMSW) produce CH_4 from CO_2 and H_2 (hydrogenotrophs) and/or from CH_3COOH (acetoclastics). The anaerobic digestion of sewage sludge for biogas production can be limited as affected by the presence of heavy metals. This is attributed to the rapid poisoning of the several active bacteria forms in the digester.

Organic solid state fermentation (SSF) is presented as a promising technology for organic waste. The utilization of household food wastes with high dry content to produce high yields of ethanol by SSF valorization is achieved via the bioconversion of these wastes. Microorganisms play an important role in the degradation of organic wastes into their constituents to convert them into high value-added products.

Most countries worldwide are facing a serious challenge to manage domestic food waste. Domestic bread wastes have been used to produce amylase. By using orange peel as a substrate the cultivation of selected industrial yeast strains resulted in a high yield of aroma esters. Mixed food wastes collected from restaurants and inoculated with fungal inoculum can produce glucoamylase-rich media and protease-rich media by SSF. These media are suitable to be used as a feedstock to produce succinic acid. The later has a wide range of applications in medicine production, plastics, and laundry detergents.

Treatment technology of such organic waste, using larvae of the black soldier fly: *Hermetia illucens*, is an important way as feasible and sustainable treatment option. Valorization of organic matter solid waste can be accomplished via composting and anaerobic digestion. The advantage of producing compost is the technical simplicity of the process. To cover part of the integrated solid waste management strategies costs, it was found that valorizing and recycling activities, has turned into a valuable income.

Acknowledgement

The authors wish to express their deep appreciation and gratitude to the facilities provided by the project titled *(Sustainable Development for Wastewater Treatment and Reuse via Constructed Wetlands in Sinai* (SWWTR)) that is funded by STDF of Egypt.

References

[1] L.A. Guerrero, G. Maas, W. Hogland, Waste Manage. (Oxford) 33 (2013) 220–232.

[2] Z. Minghua, F. Xiumin, A. Rovetta, H. Qichang, F. Vicentini, L. Bingkai, A. Giusti, L. Yi, J. Waste Manage. 29 (2009) 1227–1233.

[3] M. Sujauddin, M.S. Huda, A.T.M. Rafiqul, J. Waste Manage. 28 (2008) 1688–1695.

[4] S.J. Burntley, J. Waste Manage. 27 (10) (2007) 1274–1285.

[5] American Society of Mechanical Engineers (ASME), Waste to Energy, Summary Report Accessed July 5, 2014 http://www.asme.org, 2014.

[6] S.J. Kumar, K.V. Subbaiah, P.V.V. Rao, J. Environ. Sci. 1 (2) (2010) 26–28.

[7] U.S. Environmental Protection Agency, Wastes – Non-Hazardous Waste – Municipal Solid Waste, 1200 Pennsylvania Ave., N. W. Washington, DC 20460, U.S.A. (2013).
[8] A.B. Nabegu, J. Hum. Ecol. 31 (2) (2010) 111–119.
[9] C. Valkenburg, C.W. Walton, B.L. Thompson, M.A. Gerber, S. Jones, D.J. Stevens, Municipal solid Waste (MSW) to Liquid Fuels Synthesis, Pacific Northwest National Laboratory, Richland, WA, 2008.
[10] I.A. Al-Khatib M. Monou S.F. Abdul Q.S. Hafez K. Despo Solid, waste characterization, quantification and management practices in developing countries. A case study Nablus district – Palestine 2010.
[11] C.M. Liyala, Modernizing Solid Waste Management at Municipal Level: Institutional arrangements in urban centers of East Africa PhD Thesis, Environmental Policy Series. Wageningen University, The Netherlands, 2011.
[12] J. Okot-Okumu, R. Nyenje, Habit. Int. 35 (2011) 537–543.
[13] F.P. Sankoh, X. Yan, A.M.H. Conteh, J. Environ. Prot. 3 (2012) 562–568.
[14] E. Gidarakos, G. Havas, P. Ntzamilis, Waste Manage. 26 (6) (2006) 668–679.
[15] L. Dahlén, Household Waste Collection Factors and Variations, Department of Civil, Mining and Environmental Engineering Division of Waste Science and, Technology Luleå University of Technology, Luleå, Sweden, 2008.
[16] European Environmental Agency (EEA), Managing Municipal Solid Waste—A Review of Achievements in 32 European Countries; EEA Report No. 2/2013, Publications Office of the European Union, Luxembourg, 2013.
[17] D. Khan, A. Kumar, S.R. Samadder, Waste Manage. 49 (2016) 15–25.
[18] R. Zhang, H.M. El-Mashad, K. Hartman, F. Wang, G. Liu, C. Choate, et al., Bioresour. Technol. 98 (2006) 929–935.
[19] W. Russ, R. Meyer-Pittroff, Crit. Rev. Food Sci. Nutr. 44 (2004) 57–62.
[20] M. Banar, A. Ozkan, Environ. Eng. Sci. 25 (2008) 1213–1220.
[21] S.S. Nas, A. Bayram, Waste Manage. 28 (2008) 2435–2442.
[22] L. Rigamonti, S. Ferreira, M. Grosso, R. Cunha, R.C. Marques, J. Clean. Prod. 87 (2015) 533–541.
[23] N.P. Thanh, Y. Matsui, T. Fujiwara, Vietnam J. Environ. Manag. 91 (2010) 2307–2321.
[24] S. Ferreira, M. Cabral, N.F. Cruz, P. Simões, R.C. Marques, Waste Manage. 34 (2014) 1725–1735.
[25] B. Gu, H. Wang, Z.Z. Chen, S. Jiang, W. Zhu, M. Liu, Y. Chen, Y. Wu, S. He, R. Cheng, et al., Resour. Conserv. Recycl. 98 (2015) 67–75.
[26] H. Cheng, Y. Hu, Bioresour. Technol. 101 (2010) 3816–3824.
[27] Y. Geng, F. Tsuyoshi, X. Chen, J. Clean. Prod. 18 (2010) 993–1000.
[28] S.E. Yay, J. Clean. Prod. 94 (2015) 284–293.
[29] A. Jadoon, S.A. Batool, M.N. Chaudhry, J. Mater. Cycles Waste 16 (2014) 73–81.
[30] K. Miezah, K. Obiri-Danso, Z. Kádár, B. Fei-Baffoe, M.Y. Mensah, Waste Manage. 46 (2015) 15–27.
[31] G. Gómez, M. Meneses, L. Ballinas, F. Castells, Waste Manage. 29 (2009) 2018–2024.
[32] M. Alamgir, A. Ahsan, Electron. J. Environ. Agric. Food Chem. 6 (4) (2007) 1945–1956.
[33] T. Hazra, S. Goel, J. Waste Manage. 29 (2009) 470–478.
[34] R.K. Henry, Z. Yongsheng, D. Jun, J. Waste Manage. 26 (2006) 92–100.
[35] M.R.A. Moghadam, N. Mokhtarani, B. Mokhtarani, Iran J. Waste Manage. 29 (2009) 485–489.
[36] M. Sharholy, K. Ahmad, G. Mahmood, R.C. Trivedi, J. Waste Manage. 28 (2008) 459–467.
[37] S. Chung, C. Lo, J. Waste Manage. 28 (2008) 272–281.
[38] T. Tadesse, A. Ruijs, F. Hagos, North. Ethiop. J. Waste Manage. 28 (2008) 2003–2012.
[39] D. Pokhrel, T. Viraraghavan, J. Waste Manage. 25 (2005) 555–562.
[40] A. Brems, J. Baeyens, R. Dewil, Thermal Science 16 (3) (2012) 669–685.
[41] K. Everaert, J. Baeyens, Therm. Process. Chemosphere 46 (3) (2002) 439–448.
[42] A.A. Vucinic, A. Hublin, N. Ruzinski, Therm. Sci. 14 (3) (2010) 681–691.
[43] A.M. Raggossnig, C. Wartha, R. Pomberger, Waste Manage. Res. 27 (9) (2009) 914–921.
[44] G. Obersteiner et al., Waste Manage. (Oxford) 28 (8) (2007) S58–S74.
[45] J. Morris, Int. J. Life Cycle Assess. 10 (4) (2005) 273–284.
[46] O. Eriksson, G. Finnveden, Energy Environ. Sci. 2 (9) (2009) 907–914.
[47] H. Weigand, J. Fripan, I. Przybilla, C. Marb, Composition and Contaminant Loads of Household Waste in Bavaria, Germany: Investigating Effects of Settlement Structure and Waste Management Practice, Proc. of the 9th International Waste Management and Landfill Symposium, Cagliari, 2003.
[48] H.I. Abdel-Shafy, M.S.M. Mansour, J. Sci. Ind. Res. 76 (2017) 119–127.
[49] H.I. Abdel-Shafy, Egypt. J. Chem. 58 (1) (2015) 1–12.
[50] H.I. Abdel-Shafy, M.A. El-Khateeb, M.S.M. Mansour, Water Sci. Technol. 74 (3) (2016) 586–594.
[51] US Code. (1976). Solid Waste Disposal Act, as amended. Resource Conservation and Recovery Act: Subtitle D (Solid Waste Program). US Code (Acts of Congress) Title 42, Chapter 82, Subchapter I (Section 6901); 1976.
[52] R.J. Slack, J.R. Gronow, N. Voulvoulis, Sci. Total Environ. 337 (1–3) (2005) 119–137.
[53] T. Blundell, Chemicals in Products: Safe Guarding the Environment and Human Health 24th Report, Royal Commission on Environmental Pollution, London, UK, 2003.
[54] A. Zacarias-Farah, E. Geyer-Allely, J. Clean. Prod. 11 (2003) 819–827.
[55] R.J. Slack, J.R. Gronow, N. Voulvoulis, Crit. Rev. Env. Sci. Technol. 34 (2004) 419–445.
[56] M.A. Barlaz, B.F. Staley, F.L. de los Reyes, Anaerobic Biodegradation of Solid Waste, in: R. Mitchell, J. Gu (Eds.), Environ. Microbiol., Wiley-Blackwell, Hoboken, NJ, 2010, pp. 281–299.
[57] A. Scheinberg, D.C. Wilson, L. Rodic, Solid Waste Management in the World's Cities. Water and Sanitation in the World Cities, Earthscan Published for UN-Habitat, London, UK, 2010.
[58] P.L. González-Torre, B. Adenso-Díaz, Waste Manage. (Oxford) 25 (1) (2005) 15–23.
[59] I. Nissim, T. Shohat, Y. Inbar, J. Waste Manage. 25 (2005) 323–327.
[60] N. Matete, C. Trois, J. Waste Manage. 28 (2008) 1480–1492.
[61] K. Hadjibiros, D. Dermatas, C.S. Laspidou, Glob. NEST J. 13 (2) (2011) 150–161.
[62] J.P. Senzige, Y. Nkansah-Gyeke, D.O. Makinde, K.N. Njau, Int. J. Environ. Protect. Policy 2 (5) (2014) 147–152.
[63] A.A. Alqader, J. Hamad, Int. J. Environ. Sci. Develop. 3 (2) (2012) 172–176.
[64] S.C. Doğruparmak, M.K. Yenice, E. Durmuşoğlu, B. Özbay, H.O. Öz, Pol. J. Environ. Stud. 20 (2) (2011) 479–484.
[65] K. Mahmood, S.A. Batool, M.N. Chaudhry, A. Daud, Pol. J. Environ. Stud. 24 (2) (2015) 879–886.
[66] S. Zhao, L. Duo, Pol. J. Environ. Stud. 24 (1) (2015) 413–417.
[67] V. Francois, G. Feuillade, N. Skhiri, T. Lagier, G. Matejka, J. Hazard. Mater. B 137 (2) (2006) 1008–1015.
[68] H.F. Cheng, Y.G. Zhang, A.H. Meng, Q.H. Li, Environ. Sci. Technol. 41 (21) (2007) 7509–7515.
[69] C. Riber, C. Petersen, T. Christensen, Waste Manage. (Oxford) 29 (2009) 1251–1257.
[70] F. Philippe, M. Culot, Resour. Conserv. Recycl. 54 (2) (2009) 73–78.
[71] E. Baldwin, W. Dripps, Resour. Conserv. Recycl. 65 (2012) 107–115.
[72] R. Marques, P. Simoes, Waste Manage. Res. 27 (2009) 188–196.
[73] P. Simoes, R. Marques, J. Environ. Manage. 106 (2012) 40–47.
[74] S. Fudala-Ksiazek, M. Pierpaoli, E. Kulbat, A.A. Luczkiewicz, Waste Manage. 49 (2016) 516–529.
[75] H.K. Ozcan, S.Y. Guvenc, L. Guvenc, G. Demir, Sustainability 8 (2016) 1044–1055.
[76] Y. Hui, W. Li'ao, S. Fenwei, H. Gang, Waste Manage. (Oxford) 26 (2006) 1052–1062.
[77] UNEP, Trends in Solid Waste Management: Issues, Challenges and Opportunities. International Consultative Meeting on Expanding Waste Management Services in Developing Countries 18–19 March 2010 Tokyo, Japan (2010).
[78] L. Rushton, Br. Med. Bull. 68 (2003) 183–197.
[79] L. Giusti, Waste Manage. 29 (8) (2009) 2227–2239.
[80] R.A.D. Arancon, C.S.K. Lin, K.M. Chan, T.H. Kwan, R. Luque, Energy Sci. Eng. 1 (2) (2013) 53–71.
[81] H.I. Abdel-Shafy, Environmental transformation of bioenergy via the anaerobic digestion, in: M. Richardson (Ed.), Environment Xenobiotic, Taylor & Francis Ltd. Publisher, London, 1996, pp. 95–119.
[82] J.C. Serrano-Ruiz, R. Luque, J.M. Campelo, A.A. Romero, Challenges 3 (2012) 114–132.
[83] T.N. Glasnov, C.O. Kappe, Chem. Eur. J. 17 (2011) (1968) 11956–11961.
[84] D. Mohan, C.U. Pittman, P.H. Steele, Energy Fuels 20 (2006) 848–889.
[85] H.S. Heo, H.J. Park, Y.K. Park, C. Ryu, D.J. Suh, Y.W. Suh, et al., Bioresour. Technol. 101 (2010) S91–S96.
[86] M.H. Cho, S.H. Jung, J.S. Kim, Energy Fuels 24 (2009) 1389–1395.
[87] E. Kantarelis, A. Zabaniotou, Bioresour. Technol. 100 (2009) 942–947.
[88] R. Luque, J.A. Menendez, A. Arenillas, J. Cot, Energy Environ. Sci. 5 (2012) 5481–5488.
[89] A. Bhatnagar (Ed.), Application of Adsorbents for Water Pollution Control, Bentham Sci Pub, Sharjah, UAE, 2012.
[90] H.I. Abdel-Shafy, G. Schories, M.S. Mohamed-Mansour, V. Bordei, Desalin. Water Treat. 56 (2015) 305–314.
[91] C. Ihemouchen, H. Djidjelli, A. Boukerrou, F. Fenouillot, C. Barres, J. Appl. Polymer Sci. 128 (2012) 2224–2229.
[92] E. Rosello-Soto, M. Koubaa, A. Moubarik, R.P. Lopes, J.A. Saraiva, N. Boussetta, N. Grimi, F.J. Barba, Trends Food Sci. Technol. 45 (2015) 296–310.
[93] A. Bhatnagar, F. Kaczala, W. Hogland, M. Marques, C.A. Paraskeva, V.G. Papadakis, M. Sillanpää, Environ. Sci. Pollut. Res. 21 (2014) 268–298.
[94] T. Ahmad, M. Danish, M. Rafatullah, A. Ghazali, O. Sulaiman, R. Hashim, M. Ibrahim, Environ. Sci. Pollut. Res. 19 (2012) 1464–1484.
[95] F. Pagnanelli, S. Mainelli, F. Vegliò, L. Toro, Chem. Eng. Sci. 58 (2003) 4709–4717.
[96] A. Faaij, M. Hekkert, E. Worrell, A. van Wijk, Resour. Conserv. Recycl. 22 (1998) 47–82.
[97] Intergovernmental Panel on Climate Change, IPCC, Climate Change: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.
[98] E. Favoino, D. Hoggs, Waste Manage. Res. 26 (1) (2008) 61–69.
[99] A. Faaji, Mitig. Adapt. Strat. Glob. Change 11 (2) (2006) 343–375.
[100] S.I. Mussatto, L.F. Ballesteros, S. Martins, J.A. Teixeira, Use of agro-industrial wastes in solid-state fermentation processes, in: Industrial Waste, In Tech, Rijeka, Croatia, 2012, pp. 121–141.
[101] Eco-Cycle, Waste of Energy-Why Incineration Is Bad for Our Economy, Environment and Community, Eco-Cycle, Boulder County, CO, USA, 2011, pp. 1–20.
[102] A. Sánchez, A. Artola, X. Font, T. Gea, R. Barrena, D. Gabriel, M.Á. Sánchez-Monedero, A. Roig, M.L. Cayuela, C. Mondini, Environ. Chem. Lett. 13 (2015) 223–238.

[103] E. Giuntini, M. Bazzicalupo, M. Castaldini, A. Fabiani, N. Miclaus, R. Piccolo, G. Ranalli, F. Santomassimo, S. Zanobini, A. Mengoni, Ann. Microbiol. 56 (2006) 83–88.
[104] L. Thomas, C. Larroche, A. Pandey, Biochem. Eng. J. 81 (2013) 146–161.
[105] H.Z. Chen, Q. He, J. Chem. Technol. Biotechnol. 87 (2012) 1619–1625.
[106] U. Hölker, J. Lenz, Curr. Opin. Microbiol. 8 (2005) 301–306.
[107] R.R. Singhania, A.K. Patel, C.R. Soccol, A. Pandey, Biochem. Eng. J. 44 (2009) 13–18.
[108] N.A. Yazid, R. Barrena, A. Sánchez, Waste Manage. 49 (2016) 420–426.
[109] S.S. Behera, R.C. Ray, Int. J. Biol. Macromol. 86 (2016) 656–669.
[110] R.J.S. De Castro, A. Ohara, T.G. Nishide, M.P. Bagagli, F.F. Gonçalves Dias, H.H. A. Sato, Biocatal. Agric. Biotechnol. 4 (2015) 678–684.
[111] N. Mehboob, M.J. Asad, M. Imran, M. Gulfraz, F.H. Wattoo, S.H. Hadri, M. Asghar, Afr. J. Biotechnol. 10 (2011) 9880–9887.
[112] E.B.N. Graminha, A.Z.L. Gonçalves, R.D.P.B. Pirota, M.A.A. Balsalobre, Da.R. Silva, E. Gomes, Anim. Feed Sci. Technol. 144 (2008) 1–22.
[113] J. Chang, W. Cheng, Q. Yin, R. Zuo, A. Song, Q. Zheng, P. Wang, X. Wang, J. Liu, Bioresour. Technol. 104 (2012) 587–592.
[114] J. Lio, T. Wang, J. Agric. Food Chem. 60 (2012) 7702–7709.
[115] B.R. Dave, A.P. Sudhir, M. Pansuriya, D.P. Raykundaliya, R.B. Subramanian, Bioprocess. Biosyst. Eng. 35 (2012) 1343–1353.
[116] K.S. Sunil, D.R. Vinay, A.S. Saviraj, P.K. Naik, Am. J. Mater. Sci. 5 (2015) 126–132.
[117] M.K.B. Gratuito, T. Panyathanmaporn, R.A. Chumnanklang, N. Sirinuntawittaya, A. Dutta, Bioresour. Technol. 99 (2008) 4887–4895.
[118] J.J. Abdullah, D. Greetham, N. Pensupa, G.A. Tucker, C. Du, J. Fundam. Renew. Energy Appl. 6 (2016) 206.
[119] M.V. Nguyen, B.K. Lee, Sustainability 7 (2015) 15057–15072.
[120] H. Liu, D. Chen, R. Zhang, X. Hang, R. Li, Q. Shen, Front. Microbiol. 7 (2016) 1–10.
[121] D. Daâssi, H. Zouari-Mechichi, F. Frikha, S. Rodríguez-Couto, M. Nasri, T. Mechichi, J. Environ. Health Sci. Eng. 14 (2016) 1–12.
[122] B. Ravindran, A.G. Kumar, P.S.A. Bhavani, G. Sekaran, Current 100 (2011) 726–730.
[123] F. Veana, J.L. Martínez-Hernández, C.N. Aguilar, R. Rodríguez-Herrera, G. Michelena, Braz. J. Microbiol. 45 (2014) 373–377.
[124] S. Kanwar, G. Kumar, M. Sahgal, A. Singh, Sugar Technol. 14 (2012) 304–311.
[125] G. Sathiyanarayanan, G.S. Kiran, J. Selvin, G. Saibaba, Int. J. Biol. Macromol. 60 (2013) 253–261.
[126] A. Elmekawy, L. Diels, H. De Wever, D. Pant, Environ. Sci. Technol. 47 (2013) 9014–9027.
[127] S.K. Panda, S.S. Mishra, E. Kayitesi, R.C. Ray, Environ. Res. 146 (2016) 161–172.
[128] A. Singh, A. Kuila, S. Adak, M. Bishai, R. Banerjee, Agric. Res. 1 (2012) 213–222.
[129] T. Nidheesh, G.K. Pal, P.V. Suresh, Carbohydr. Polym. 121 (2015) 1–9.
[130] P. Esakkiraj, R. Usha, A. Palavesam, G. Immanuel, Food Bioprod. Process. 90 (2012) 370–376.
[131] H.I. Abdel-Shafy, R.O. Aly, Wastewater management in Egypt, in: M.K. Zaidi (Ed.), Wastewater Reuse-Risk Assessment, Decision-Making and Environmental Security, Springer Publisher, Netherland, 2007, pp. 375–382.
[132] H.I. Abdel-Shafy, M.S.M. Mansour, J. Sustainable Sanit. Pract. 14 (2013) 17–25.
[133] M. Melikoglu, C.S.K. Lin, C. Webb, Food Bioprod. Process. 95 (2015) 63–75.
[134] A. Cerda, M. El-Bakry, T. Gea, A. Sánchez, J. Environ. Chem. Eng. 4 (2016) 2394–2401.
[135] F.T. Mantzouridou, A. Paraskevopoulou, S. Lalou, Biochem. Eng. J. 101 (2015) 1–8.
[136] L. Matsakas, P. Christakopoulos, Sustainability 7 (2015) 1446–1458.
[137] Z. Sun, M. Li, Q. Qi, C. Gao, C.S.K. Lin, Appl. Biochem. Biotechnol. 174 (2014) 1822–1833.
[138] T.I.N. Ezejiofor, C.I. Duru, A.E. Asagbra, A.N. Ezejiofor, O.E. Orisakwe, J.O. Afonne, E. Obi, Afr. J. Biotechnol. 11 (2012) 10115–10124.
[139] W. Zhang, H. Zou, L. Jiang, J. Yao, J. Liang, Q. Wang, Biotechnol. Bioprocess Eng. 20 (2015) 1123–1132.
[140] S. Diener, C. Zurbrugg, K. Tockner, Waste Manage. Res. 27 (2009) 603–610.
[141] NC State University. Technology Report: Black Soldier Fly (SF) (2006).
[142] H.M. Myers, J.K. Tomberlin, B.D. Lambert, D. Kattes, Environ. Entomol. 37 (1) (2008) 11–15.
[143] C. Gowe, Food Sci. Qual. Manage. 45 (2015) 47–61.
[144] L. Cooperband, Building soil organic matter with organic amendments. Center for Integrated Agricultural Systems, University of Wisconsin-Madison, Madison, 2002, pp. 1–16.
[145] Y. Vögeli, C.R. Lohri, A. Gallardo, S. Diener, C. Zurbrügg, Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland, 2014.
[146] H.I. Abdel-Shafy, M.S.M. Mansour, Egypt. J. Petrol. 23 (4) (2014) 409–417.
[147] F.A. Nasr, H.I. Abdel-Shafy, Environ. Manage. Health 3 (4) (1992) 18–25.
[148] Sustainable Bachmann biogas production in municipal wastewater treatment plants IEA Bioenergy ISBN 2015 978-1-910154-22-9. http://www.iea-biogas.net.
[149] International Energy Agency, IEA BIOENERGY TASK 37, Biowaste and sewage sludge recovery: separate digestion, common gas upgrading and heat supply, Case Study, (2014). Available from: http://www.ieabiogas.net/case-studies.html.
[150] C. Rich, J. Gronow, N. Voulvoulis, Waste Manage. (Oxford) 28 (6) (2008) 1039–1048.
[151] J. Anschütz, J. Ijgosse, A. Scheinberg, Putting ISWM to Practice, WASTE, Gouda, The Netherlands, 2004.
[152] Z.Y. Zhang, B. Jin, J.M. Kelly, Biochem. Eng. J. 35 (2007) 251–263.
[153] J. Zhuang, M.A. Marchant, S.E. Nokes, H.J. Strobel, Appl. Eng. Agric. 23 (2007) 679–687.
[154] A.M. De Castro, D.F. Carvalho, D.M.G. Freire, L.D.R. Castilho, Enzyme Res. 2010 (2010) 1–9.
[155] A. Ali, Managing the scavengers as a resource. In: T. A. G. Kocasoy, and İ. Nuhoğlu (Eds.), Appropriate Environmental and Solid Waste Management and Technologies for Developing Countries, İstanbul, (2002) pp. 730.
[156] UN-HABITAT, Solid Waste Management in the World's Cities, Earthscan, London and Washington, DC, 2010.
[157] M. Prein, M. Ahmed, Food Nutr. Bull. 21 (2000) 466–471.
[158] M. Ahmed, M.H. Lorica, Food Policy 27 (2) (2002) 125–141.
[159] S. Kroeckel, A.G.E. Harjes, I. Roth, H. Katz, S. Wuertz, A. Susenbeth, C. Schulz, Aquaculture 364–365 (2012) 345–352.