

Solid Waste Management at University Campus (Part 7/10): Food Waste and Preliminary Design of Aerobic Composter

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Abstract
Food-wastage is a-*global*-predicament, of overwhelming-magnitude, which indeed, leaves very-deep- footprint, as Carbon and water-trail, alongside-with stressing land-resources, and negatively-affecting biodiversity. Besides-its-footprints, food-wastage has both; a-financial and a-social-cost, *not* to-mention its-contribution to global-hunger. In-the-context of the-subject-university, food-waste-share in the-total- waste, is 37%, accounting to 1,891.31 tons/per year, on-average. Moreover, an-average-moisture-content of the-food-waste found at 57. 66%, hence such-waste *cannot* be combusted, without auxiliary-fuel. Currently mixed-waste, including food-waste, at the-university, is just disposed-off, at the-dumpsite, without any-formal waste-reduction, separation, at-source, recycling, or composting. To-recommend sustainable-amendments of the-current waste-management-system, this-study is focused on food-waste- analysis (at-retail and consumer-level). As-such, the-typical 'Food wastage along the-supply-chain' was analyzed and modified, to-incorporate transportation-component, alongside *every* element of the-chain. The-study also observed some-disrespectful-practices, towards-food, pointing-out at possible-lack of value for food, demonstrated by many-students, in-the-campus, in-the-form of large-amount of unceremoniously-discarded perfectly-edible 'leftovers'. The-study also-emphasized, that food is simply too-precious and valued to-be-wasted. All-the-management-approaches, offered by the-Food-Waste Recovery-Hierarchy, were evaluated, and it was concluded, that in-the-local-context, composting is the-most-affordable, socially-acceptable, safe, and hence, preferable-method of food-waste-treatment. The-study, furthermore, conducted a-preliminary-design of a-small-scale, low-tech, aerobic, in-vessel, rotary-drum-composter, to-generate 'green' fertilizers and simultaneously-reduce food-waste-burdens, at-the-campus. Recommendations for food-waste-reductions, as-well-as areas for further-research, are offered. The-findings of this-research provide a-necessary-baseline-data, for the-three subsequent-studies, in-the-series, and will inform decision-making-processes, during designing and implementation of food-waste reduction-strategies, and, hopefully, also-contribute (in its-small-way) to-the-body of knowledge, on the-subject-matter.
Keywords: Food Waste Recovery Hierarchy; Post harvest losses (PHL); Plate Waste; Global warming.

1. Introduction.

1.1. Global-Food-Crisis.

Paradoxically, about 15% of population in-developing-countries, is starving (FAO, 2012), while a-growing-number of countries is dealing with over-consumption of food, food-related-diseases (e.g., obesity), and increasing food-waste-generation. The-United-Nations Population-Division (UNPD) predicts that the-global-population will-increase-steadily, from 7.2 billion-people in-2013, to 9.6 billion by 2050 (UNPD, 2013). Consequently, the-world's food-production-system is faced with a-huge-challenge, to-meet the-nutritional-needs of this ever-increasing-population. The-global food-demand is projected to-increase by 60% - 110%, between 2005 and 2050, mainly due-to population-growth and diet-shifts (Godfray *et al.,* 2010). The-Food and Agricultural-Organization (FAO, 2006) trusts there is a-need to-increase world-food- production by about 70% in 2050, to-meet the-growing-deficit, between demand and supply. However, current-widespread-focus on increased-food-production, as the-*main*-strategy, to-reduce food-insecurity, has-been-criticized (Soil-Association, 2010; Lundqvist *et al.,* 2008), as considerable-evidence exist, that increasing-food-production, alone, may *not* necessarily improve global-food-security (RSIS, 2013).

As a-solution to this-dilemma, FWRA (2014) explored a-range of options that must-be-put in-place to-synergistically work to-avert the-impending global-food-crisis (Searchinger *et al.,* 2013), and also enhance socio-economic-development, while concurrently-protecting the-environment. At the-very-top of this-range is reducing food-losses and food-waste. According-to Lundqvist *et al.* (2008), the most-often quoted-estimate is that: 'as much as half of all food grown is lost or wasted before and after it reaches the consumer'. Such-estimates are difficult to-scrutinize, but they call for greater-resource-efficiencies, in the-global-food-supply-chain (FSC). In-this-regard, Lundqvist *et al.* (2008) encourage increased-efficiency in global-FSC, to-reduce food-wastage. Moreover, the-United-Nations Sustainable Development Goal 12 (SDG 12) on "Ensuring sustainable consumption and production patterns" includes a-specific-food-waste reduction-target: "by 2030, to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses".

1.2. Relevant-definitions.

Several-definitions, used in this-study, have to-be-clarified, such-as: (i) *Food loss:* indicates a-reduction in-mass (quantity) and/or nutritional-significance (quality) of food, thus making food, originally-intended, for human-consumption, unfit for consumption (FAO, 2013); (ii) *Food waste,* also referred-to-as garbage, swill, and/or kitchen-waste (Price *et al*., 1985; Kornegay *et al*., 1965), indicates food that is fit for human- consumption, but is discarded before-consumption, mainly because the-food has expired, or was consciously, or unconsciously, left to-spoil (Lipsinki *et al.,* 2013; FAO, 2013); (iii) *Food wastage:* indicates food, lost either; through-deterioration (in-quantity and quantity), or discard. Accordingly, 'food wastage' includes both; food-losses and food-waste (FAO, 2013). Besides, Bond *et al.* (2013) define food-losses and wastes as: "edible food products, which are intended for purposes of human consumption, but have instead been discarded, lost, degraded, or consumed by pests, and does not include the inedible or undesirable portions of foodstuffs." A close-examination reveals, that this-definition is a-combination of the-above- definitions, thus, it adequately-describes food-losses and wastes. This-definition is, hence, adopted by the-study; (iv) *Food leftovers:* refer-to food, which is prepared, but never-served (Engström & Carlsson-Kanyama, 2004); (v) *Serving losses:* refer to food, that is left on preparation and/or serving utensils (spoons, dishes, or bowls) (Youngs *et al.,* 1983); (vii) *Food Plate Waste (FPW):* denotes food, that is served, but left-uneaten and discarded. Elsewhere, plate-waste is also-referred-to as post-consumer food-waste or 'table-scraps' (LeanPath, 2012); and (viii) *Food supply chain:* a-system of organizations, people, and activities, which moves food, from its-initial-producer (ordinarily the-farmer) to the-final- consumer (Beretta *et al.,* 2012; Mena *et al.,* 2011).

1.3. Food wastage, along the supply chain: Global scenario.

Food-wastage is mainly-associated-with inefficiencies within the-Food-Supply-Chain (FSC). **Figure 1** shows food-wastage along the-supply-chain. Food-losses and wastes occur, throughout the-food-supply chain, from production to distribution to the-market, and consumption (Engstrom & Carlsson-Kanyama, 2004; Kantor *et al.,* 1997). These include: poor/ inappropriate logistics and infrastructure; insufficient-knowledge, skills, and technology, by the-actors, along the-FSC. In-some-cases, changes in-weather-patterns and natural-disasters influence food-losses. Food-waste often due to-the-food, that has spoiled, *but* it can be for other-reasons, such-as: oversupply, due-to-markets, or individual-consumer shopping/eating-habits (FAO, 2013). A-general-understanding, exists in-literature that food-losses predominantly-occur in less-developed-countries, whereas food-waste is seen as a-problem in- industrialized-countries (Gustavsson *et al.,* 2013; Lipinski *et al.,* 2013; Parfitt *et al.,* 2010). For-example, fresh-products like fruits, vegetables, meat, and fish, straight-from-the-farm, or after the-catch, can be spoiled in-hot-climates, due-to-lack of infrastructure for transportation, storage, cooling/refrigeration, and markets (Ahnberg & Strid, 2010; Stuart, 2009; Rolle, 2006).

This-study is focused on 'Post-harvest'-food waste, starting from Wholesale/retail up-to End of life/disposal. In-particular, the-scope of this-study is limited to points # 5, 6a, 6b, and # 7, shown in the- **Figure 1**.

Figure 1: Food wastage along the supply chain (FAO toolkit, 2013).

Unlike most-other-commodity-flows, food is a-biological-material, subject to degradation (Parfitt *et al.,* 2010). Food-loss and waste can-occur, at each-stage of the-food-value-chain (see **Figure 1**). For-example (Gunders, 2012; Kummu *et al.,* 2012; World Bank, 2011; FAO, 2011): (i) During *production* or harvest, in-the-form of grain, left-behind, by poor-harvesting-equipment, discarded-fish, and fruit *not* harvested or discarded, because they fail-to-meet quality-standards, or are uneconomical to-harvest; (ii) During handling and storage, in-the-form of food, degraded by pests, fungus, and disease; (iii) During processing and packaging, in-the-form of spilled-milk, damaged fish, and fruit, unsuitable for processing. Processed-foods may be lost or wasted, because of poor-order-forecasting and inefficient-factory-processes; (iv) During distribution and marketing, in-the-form of edible-food discarded, because it-is non-compliant with aesthetic-quality-standards, or is *not* sold before 'best before' and 'use-by' dates; and (v) During consumption, in-the-form of food, purchased by consumers, restaurants, and caterers, but *not* eaten.

It-is important to-note, that food-waste or loss is measured *only* for products, which are directed to human-consumption, excluding feed, and parts of products, which are *not* edible. Food that was originally meant to-human-consumption, but which fortuity gets out the-human-food-chain, is considered as food loss or waste, even if it-is then directed to a-non-food-use (e.g., animal-feed, bio-energy, etc.). This-approach distinguishes 'planned' non-food-uses to 'unplanned' non-food-uses, which are hereby accounted under-losses (Ahnberg & Strid, 2010; Parfitt *et al*., 2010).

On-the-other-hand, the-method of measuring the-quantity of post-harvest food-wastage is usually by-weight, although other-units of measure include: calorific-value, quantification of greenhouse-gas- impacts, and lost-inputs (e.g., nutrients and water) (Parfitt *et al.,* 2010; WRAP, 2009b). Rigorous-data on the-scale of food-wastage, across the-supply-chain, is currently lacking. This is primarily due-to the-lack of a-universal-method of measuring food-waste, at the-country-level, and across the-different-levels of the-food-production and consumption. Equally, nations and corporations are under *no* obligation to-report their-food wastage-data (Hudson & Messa, 2015).

In-particular, FAO (2011) reports, that: (i) roughly one-third of food, produced for human- consumption, is lost, or wasted, globally, accounting to about 1.3 billion tons, per-year; (ii) the per-capita food-waste, by consumers, in-Europe and North-America, is 95-115 kg/year, while this-figure in- sub-Saharan-Africa and South/Southeast-Asia is *only* 6-11 kg/year; and (iii) there are major-data-gaps, in- the-knowledge of global-food loss and waste; further-research in the-area is urgent.

Besides, food-waste is a-*global*-predicament of overwhelming-magnitude. For-example: Japan's households and food-industry, together, discard nearly 17 million-metric-tons of edible-food, annually, an-estimated 30% of their-total-production (MAFF, 2012; Morisaki, 2011; Srinivas, 2010). In-India, nearly 30% of the-country's fruits and vegetables are lost, due-to lack of cold-storage-facilities, and more than 30% of the-grain, supplied through the-public-distribution-system, is lost as-well (Mukherji & Pattanayak, 2011). Food-waste in-China has increased rapidly, and now accounts for about 70% of household and commercial- waste (Xin *et al.,* 2012). The-amount of food-wasted, per-year, in-UK-households is 25% of that purchased (by weight) (WRAP 2008; 2009 a; 2009 b). Fresh-fruits, vegetables, and salads, make-up the-largest category of food-waste, according to the-UK's Waste & Resources Action-Program (WRAP) report, accounting for 1.4 million-ton, per-year (Moore, 2008). The-US Environmental-Protection-Agency estimated that food-waste, in 2008, accounted for 12.7% (31.79 Mt) of municipal-solid-waste-stream (US-EPA, 2009). Australia, a-submission to the-Senate inquiry estimated, that food-waste comprises 15% of the 20 Mt of waste, which goes to-landfill, each-year (Morgan, 2009). Dutch-consumers throw-away approximately 8-11% of food, purchased, equating to 43-60 kg of food-waste with an-average-value of EURO 270–400 per-person, per-year (Thonissen, 2009). A-study by UN-FAO (Pekcan *et al.,* 2006), in-Turkey, estimated the-average daily-discards, per-household, and per-person, were 816.4 and 318.8 g, respectively.

Consumer-food-waste is, indeed, the-greatest-contributor to overall-food-wastage (Gustavsson *et al.,* 2013; Gunders, 2012; FAO, 2011; Kantor *et al.,* 1997); estimated between 4 and 60% of total-food-volumes, they purchase (Gustavsson *et al.,* 2013; Schneider, 2013; Gunders, 2012; Williams & Walton, 2011; Stuart, 2009). Kantor *et al.* (1997) reported that food-waste, in-households, and food-service industries, constitute 26 % of the-total-waste. In-America, an-average-family (consisting of four-people) throws-away up to 25% of their-food and beverage-purchases, and this-is-estimated to-cost between US dollars 1,365 and 2,275 yearly (Gunders, 2012). In-Italy, about 146 kg of food is wasted, per-person, every-year (Buchner *et al.,* 2012). A-study by Engstrom & Carlsson-Kanyama (2004) found that the-Swedish food-service-industry wastes up-to one-fifth of total-food-purchases. Data for Norway, Sweden, Denmark, and Finland, combined-together, reveal that up-to 680,000 tons of food is wasted, annually, in these-countries (NCM, 2012). In-the-United-Kingdom, food-service-sector generates 0.4 million-tons of avoidable-food-waste, which economically costs Euros 722 million, yearly (Bond *et al.,* 2013). Overall, these-figures represent huge-waste of resources, and as-such, the-current-situation should-be-addressed.

Furthermore, it-is commonly-assumed that hunger and malnutrition are associated *only* with developing/ low-income-countries. Apparently, even in the-United-States, 50.1 million Americans lived in food-insecure-households (33.5 million-adults and 16.7 million-children) (Coleman-Jensen, 2012), at the-same-time about the

40 % of food produced is wasted (Gunders, 2012). Besides, according to Eurostat, 81 million-people in-Europe are threatened by poverty (which is 17% of its-population), and 42 million already live below the-poverty-line (European-Commission, 2014).

1.3. Food waste and its-impacts.

Whether it-is called food-loss, or food-waste, all this-food required energy, land, water, time, fuel/energy, natural, as-well-as human-resources, and money, to-be: produced, transported, processed, packaged, stored, sold, bought, and cooked (Hudson & Messa, 2015). Agriculture is a-significant-emitter of the-three-most important greenhouse-gases, i.e., carbon-dioxide (CO2), nitrous-oxide, and methane (Schaffnit-Chatterjee, 2011; Popp *et al.,* 2010; Audsley *et al.,* 2009), contributing to Global warming/climate-change. Eventually, food becomes food-waste/refuse, using up further-resources for its-management. According to WRAP (2008), a *single* ton of food-waste is liable for 4.5 tons of carbon-dioxide. When trucked to landfills, food decomposes into-methane - a gas, that is, at-least twenty-times, more-potent than carbon-dioxide, for global-warming (Starovoytova, 2018a; Mena *et al.,* 2011; Hall *et al.,* 2009). When buried, decaying-food causes air and water-pollution, through surface-runoff and leaching (Starovoytova, 2018b; Griffin *et al.,* 2009). These-impacts exclude those of crop-production, which include alterations to natural-landscapes and ecosystems, biodiversity-loss and increasing the-global-temperatures, which are *not* easy to-quantify (FAO, 2013; Lipsinki *et al.,* 2013). The-emissions, caused along this-chain are called 'direct' emissions (Noleppa, 2012).

A product's *carbon-footprint* is the-total-amount of greenhouse-gases (GHGs) it emits, throughout its-life-cycle, expressed in kilograms of CO_2 - equivalents. This includes the-GHG-emissions, during the-agricultural-phase, including those from on-farm energy-use, and non-energy-related-emissions (such-as CH_4 and N_2O) from soils and livestock (WRI, 2012). In-particular, in the-agro-food-sector, GHGs are comprised primarily of CO_2, generated through the-use of fossil-fuels, from methane (CH_4), derived from livestock-enteric-fermentation, and emissions of nitrous-oxide (N_2O), caused by the-use of nitrogen-based-fertilizers (Kummu *et al.,* 2012).

Global-food-wastage generates annually 4.4 Gt CO_2 eq., or about 8% of total-anthropogenic- GHG-emissions. This-means that the-contribution of food-wastage-emissions to-global-warming is almost equivalent (87%) to global-road transport-emissions (Hic *et al.,* 2016). The-average global-carbon-footprint of food-wastage is about 500 kg CO_2 eq., per-capita, per-year (FAO, 2013).This-share will increase drastically, if emerging-countries, like China and India, adopt Western-nutrition-lifestyles. GHG-emissions, associated-with food-waste could increase tremendously, from today 0.5 to 1.9 - 2.5 Gtons of CO_2 eq. per-year by 2050 (Hic *et al.,* 2016). In-Sub-Saharan-Africa food-wastage generates annually about 210 kg CO_2 eq., per-year, in-comparison with North-America & Oceania with 860, and 350kg in-South & Southeast-Asia (Godfray *et al.,* 2010). The-highest carbon-footprint of wastage occurs at the-consumption- phase (37 % of total), whereas consumption *only* accounts for 22% of total-food-wastage. At the- consumption-phase, the-GHG-emissions coming from consumption-itself (i.e., energy for cooking) play a-significant-role (FAO, 2013). In-addition, different food-products have different-carbon-footprints; for-example, one kg of wheat, or one kg of beef, have different-carbon-footprints, since their-life-cycles are different, emitting specific-types and varying-amount of greenhouse-gases. It-is also-important, to-note that the-further along-the-chain the-food-loss occurs, the-more carbon-intensive is the-wastage. For-instance, a-single-tomato, spoiled at the-harvesting-stage, will have a-lower carbon-footprint, than tomato-sauce, wasted at the-retail-store, since the harvesting, transportation, and processing, accumulates additional- greenhouse-gases, along the-supply-chain (Hic *et al.,* 2016).

Water-footprint accounting for water-use can take two-forms: withdrawal or consumption. Water-withdrawal refers to water, diverted or withdrawn, from a-surface-water or groundwater-source. Consumptive-water-use refers to water that is *no* longer-available, for the-immediate water-environment, because, for-instance, it-has-been transpired by plants, incorporated-into-products, or consumed by people or livestock, or evaporated during-irrigated-agriculture. Recent-work on the-global-water-footprint of human-activities indicates that consumption of agricultural-products is responsible for 92% of the-water-footprint of humanity (Hoekstra & Mekonnen, 2012). Although it can be pointed-out that water is also-used for food-processing (e.g., food cleaning, sanitizing, peeling, and cooling), a-large-part of this- water is released afterwards, thus limiting the-water-footprint of this-stage. The-average water-footprint of food-wastage, when considering food-crops *only*, and *not* taking animal-products into-account, is about 30 m^3 per-capita, per-year (Kummu *et al.,* 2012). Rolle (2006), pointed-out, that different-food-products have different-requirements; for-example, growing one-kg of tomatoes (requires 13 liters of water) is much-less water-intensive, than producing one kg of beef-steak (7 000 liters of water).

Land-occupation describes the-surface of land, including cropland and grassland, necessary to-produce foodstuff. More-specifically, it evaluates the-surfaces, occupied by-food, produced, *but* uneaten, because of wastage. This-land-occupation-indicator has some-advantages, since it has relatively-low- uncertainty, and is expressed in a-surface-area-unit (e.g., ha), which is easy to-understand. Land (and particularly agricultural-land) can be-seen as a-limited-natural-resource, with a-number of competing-uses (e.g., agriculture, buildings, roads, etc.). Assessing land-occupation provides a-view on the-depletion of this-resource (Mattila *et al.,* 2011). At the-global-level, the-total-amount of food-wastage in 2007, occupied almost 1.4 billion-hectares, equal to about 28 % of the-world's total-agricultural-land-area. According-to the-World-Economic-Forum (2014), food-loss and waste, claims 20% of freshwater-consumption and uses 30% of the world's agricultural-land-area.

While it-is difficult to-estimate impacts on *biodiversity*, at a-global-level, food-wastage unduly compounds the-negative-externalities that mono-cropping and agriculture-expansion into wild-areas, creating biodiversity-loss. Globally food-waste may represent more than 20% biodiversity-pressure (FAO, 2013).

Besides-its-footprints, food-wastage has both; a-financial and a-social-cost, *not* to-mention its-contribution to global-hunger. In-addition-to the-monetary-value of the-food-itself (i.e., the-value of the-product at the-production stage, during-which it was wasted), the-natural-resources, embedded in the-wasted-food, also have a-value. Plus, given the-increasing-scarcity of global-resources, such-as land and water, the-price of natural-resources is going to-increase in-future. In-many-countries, water and land, already have high-costs and GHG-emissions lead to climatic-changes, which can have major-economical- implications. When considering the-entire-lifecycle of a-food-product, the-production-phase has the-largest impact on natural-resources. However, each-phase has *additional* environmental-impacts. This-implies that the-further-down one is in the-supply-chain (e.g., consumption), the-higher is the-food-wastage-footprint (FAO, 2013).

In-monetary-terms, the-FAO (2013 toolkit) estimated that in 2013, the-global-cost of producing *uneaten*-food stood at USD 750 billion.

1.4. Previous studies and purpose of the-research.

Food-waste has-been-identified as a-significant social, economic, and environmental-problem (Thyberg *et al.,* 2015), and it become a-topic of growing-interest-worldwide. A-document-analysis showed that extensive-studies on food-losses and wastes, especially at-retail and consumer-levels, have been carried-out, mainly in the-*developed*-countries, such-as: the UK (WRAP, 2009a); U.S.A. (Kantor *et al.,* 1997); Canada (Gooch *et al.,* 2010); Switzerland (Beretta *et al.,* 2012); Australia, Turkey, and South-Korea (Parfitt *et al.,* 2010). Oelofse & Nahman (2012); and Nahman *et al.* (2012) are the-examples, of studies, done in-developing-countries, South-Africa, in-particular. According-to HLPEFSN (2014), most-research is motivated *only* by invocation of the-estimated-magnitude of food-wastage and *not* by what the-magnitude means, nor by its-consequences.

The-food-waste is assessed to-cause approximately a-third of all-greenhouse-gas-emissions (Garnett, 2011). Reducing this-waste is, accordingly, listed as one of the-necessary-actions for more-sustainable food-security (Foley *et al.,* 2011; Godfray *et al.*, 2010). According-to the-Government of Kenya (2011):

> About half of Kenya's estimated 38.5 million people are poor, and some 7.5 million people live in extreme poverty, while over 10 million people suffer from chronic food insecurity and poor nutrition. In recent years, it is estimated that at any one time about two million people require assistance to access food. During periods of drought, heavy rains and/or floods, the number of people in need could double.

Institutions, specifically universities, can make an-impact on changing this-statistic. Hinged on this-premise is that universities are conducive to problem-based-learning (Ehrlich, 1998). On-the-other hand, these-institutions, themselves, consume significant-amounts of resources, particularly energy and water, and create large-amounts of waste. Among the-food-service/hospitality institutions that are characterized with high-levels of consumer-waste are colleges and universities, collectively referred to-as higher-education-institutions (HEIs) (INFORM, 1998). This has seen a-worldwide-call for HEIs to-reduce their-environmental-footprint and provide a-role-model, for the-rest of society, of sustainability-practices, due-to-their-role and status, in-society (Stephens *et al.,* 2008; Armijo de Vega *et al.,* 2003; INFORM, 1998).

This-study, therefore, is focused on examination of *all* the-management-approaches, offered by the-Food-Waste-Hierarchy, to-reduce food-waste, and to-identify the-ones, suitable/practicable for the-subject-university. The-study also highlights on the-consequences of food-waste. Information from this-research will inform decision-making-processes, during designing and implementation, of food-waste reduction-strategies.

2. Materials and Methods.

2.1. Background.

The-study was conducted at the-Moi-University (MU), situated at Kesses-Constituency, the-Uasin Gishu County, Kenya. MU is the second-largest-public-university, after the-University of Nairobi. As of 2007, it had over 20,000 students, including 17,086 undergraduates. It operates eight-campuses and two-constituent colleges (Starovoytova & Cherotich, 2016 b). The-study was conducted over a-four-week sampling-period, in-2017 calendar-year, across the-MU, *main*-campus.

Analogous to Starovoytova (2017), interested-readers could-refer to Starovoytova *et al.* (2015) to-find informative-synopsis regarding Kenya, and its-educational-system. Besides, study by Starovoytova & Cherotich (2016 a), provides valuable-particulars, on MU, where the-study was conducted. The geographical-position on the-subject-university can be accessed *via* Starovoytova & Namango (2018).

From the-previous-studies by Starovoytova & Namango (2018), and Starovoytova (2018c), food waste-share in the-total-waste, generated by the-university, is 37%, accounting to 1,891.31 tons/per year, on-average. In-particular, food-waste constituted: 77% of all the-waste, generated at Eateries/ canteens; 58% at student-hostels; 50% at Stage-market; and 7% at administration-offices. Currently mixed-waste, including food-waste, at the-university, is just disposed-off, at the-dumpsite, without any-formal waste-reduction, separation, at-source, recycling, or composting. Moreover, according to Starovoytova (2018d), an-average-moisture content of the-food-waste is 57. 66%, hence such-waste *cannot* be combusted, without auxiliary-fuel.

2.2. Methods.
To-propose the-most-appropriate food-waste-treatment-method(s), for the-local-specifics, this-study used the-relevant-data, from previous-surveys, at-the-subject-university, as-well-as document-analysis was conducted on available-technologies (offered by the-Food-Waste-Hierarchy), alongside-with examination of their-practices, and limitations. Then the-preliminary-design of the-most-appropriate-treatment-system was conducted.

The-design applied fundamental-Engineering-principles of *product*-design (for more-details see Martin, 2000; Cross, 2000; Starovoytova, 2018e; Starovoytova, 2018f; Starovoytova & Namango, 2016; Starovoytova & Njoroge, 2016; and Starovoytova *et al.,* 2014).

To-ensure a-unique-design, document-analysis was-utilized, as one-of the-study-instruments (including review of: (i) Selected-International-patents on the-designs of rotating-drum/small-scale composters and their-respective-limitations; and (ii) Published-research on aerobic-composters.

Target-specifications/objectives, of the-system, were formulated-from, and based-on the-document analysis. Design-factors, such-as availability of component-parts, ease of machine-ability, affordability, efficiency, and ease of operation, were considered in the-design. After the-determination of the-objectives, of the-device, Pair-wise Comparison Charts (PCC) was used to-rank the-importance of the-objectives, in- the-different-levels.

Afterwards, three free-hand-sketching of alternative-designs were made, and the-best alternative- design was chosen *via* Standard-Engineering-numerical weighted-decision-Matrix. This-choice was also- confirmed by ‘Drop and Re-vote’ (D&R) method, according to Filippo (2012).

The-materials-selection was done according-to Ashby (2005). According to Ashby & Johnson (2003), the-starting-point, for a-design-project, is function, which dictates the-choice of materials and shape. Shape includes both; the-external-shape (macro-shape) and the-internal-shape (e.g., honeycombs). The-properties, for consideration, were limited-to: Technical-properties of materials (density, conductivity, strength, etc.); manufacturing of materials (easy to-manufacture with existing manufacturing-facilities), economic-properties of materials (cost for material and production, availability, etc.); and ecological- properties of materials (recycle-ability, embodied-energy; sustainability, etc.). To-assist in the-selection of materials, many material-libraries are-being-build, worldwide, such-as for-example: MaterialConnexion (www.materialconnexion.com), which was used in-this-study.

Some of the-variables, considered in-the-rotating-drum composter-design, include: residence-time (based on length, diameter, and material-depth), inclination of the-axis of rotation, and the-number and the-shape of internal-blades. The-following-parameters, such-as: Maximum-volume of food-waste, that can be-composted, at a-time, was calculated according-to Khurmi & Gupta (2005), while composting-drum dimensions and shaft-diameter were determined according-to Christiana (2014); and Martin (2000).

The best-alternative-design was then optimized, based on calculations. The-layout was analyzed for forces, stresses, etc., and calculations, necessary were made, to-be-certain that the-parts can perform satisfactorily. 2D-drawings, of the-best-alternative, were created *via* computer-aided-design (CAD) AutoCADsoftware.

3. Results and Analysis.
3.1. Transportation in the-FSC and its-effects.
Analyzing the-**Figure 1**, the-study realized, that transportation (marked as # 4) is indicated in FAO’- diagram only once (from Processing to Wholesale/retail-stage). In-reality, however, transportation is also-necessary between: (i) Production and Storage; ((ii) Storage and Processing; (iii) Wholesale/retail and Food services-industries; (iv) Wholesale/retail and Household-consumption; and finally (v) food-waste have-to-be-transported from Food-services and Household-consumption to the-final-disposal, like shown in-**Figure 2** (adjusted, by the-study, to-incorporate necessary-transportation-elements).

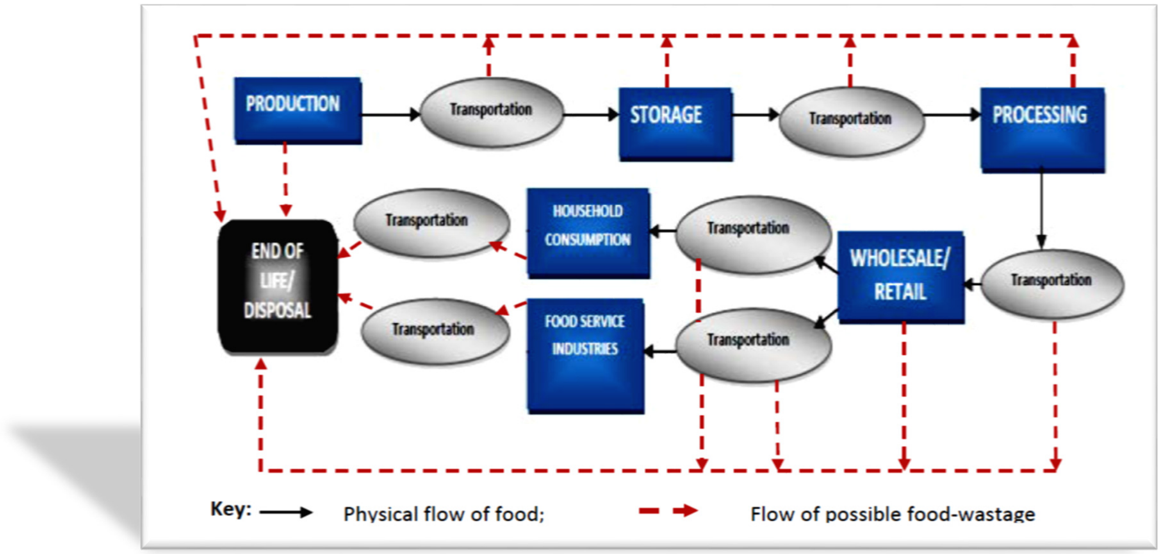

Figure 2: Modified Food-wastage along the-food-supply-chain.

From the-**Figure 2** it-is-evident that transportation plays an-indispensable-role, along the-food supply-chain. Transporting food and food-wastage, contribute in-the-same-manner to greenhouse-gas- emissions. The-difference is that while *no* methane is emitted, other-gases are. According to the-Inter- governmental-Panel on Climate-Change (IPCC, 2014) transport emits CO_2, the-most-important greenhouse gas (GHG), and if global-warming crosses the-safety-threshold of 2^0C then the-consequences could-be anywhere, between bad and catastrophic. Worldwide, in-2014, transport, as a-whole was responsible for 23% of total CO_2-emissions, from fuel-combustion, and road-transport was responsible for 20% (International Energy Agency, 2016).

According-to Andres & Padilla (2018), the-role of the-transport-activity in greenhouse-gas emissions has-been-studied broadly. The-recent-research by Eliasson & Proost (2015); Banister & Hickman (2013); Hickman *et al*. (2010); Hull (2008); Hickman & Banister (2007); and Tight *et al.* (2005) are some-examples of analysis of the-proper-design of environmental-policies, aimed at reducing transport-emissions. Other-studies focused on traffic-flow-models and simulation-models and made significant-contributions to-understand the-impacts of different-variables on emissions; some-examples are the-works by Tang *et al.* (2015, 2017); Zhu (2013); and Yu (1998). Resent-study by Santos (2017) pointed- out, that: “Two barriers have prevented substantial reductions of GHG emissions in general and in transport in particular: incomplete international agreements and the high cost of (transport) clean technologies”. To-remove/reduce these-barriers will probably take time, even if resources are available.

On-the-other-hand, improving transportation, to-reduce food-waste has many-requirements, such-as: (i) improving the-means of transportation (e.g., boat, rail, air, and roads); (ii) the-condition of transportation (e.g., refrigerated-vehicles); and (iii) reducing the-number of kilometers, to-be-covered by creating market-options closer to-the-production-place.

In-terms of environmental-impact, improving transportation can-be rather-complex (FAO, 2013). To-reduce their-environmental-footprint, suppliers can consolidate their-operations, increase their-use of rail and water-transit, and increase transport-efficiency (Wakeland *et al.,* 2012). When-possible, creating shorter-supply-chains can have the-best-economic and environmental-impact, while improving food- security. Moreover, distance is *only* one of the-parameters that determine the-ecological-impact of transport. It-is-also important to-consider, for-example, transport-modes, the-type of fuel-used, and the-filling-rate of the-vehicles (Blanquart *et al.,* 2010), alongside-with the-overall-logistics for transportation.

3.2. Food Waste Recovery/Management.

According-to the-FAO (2013), prevention of food-waste decreases utilization of the-natural-resources, involved in food-production. Most-importantly, reducing food-wastage lessens the-threatening ecological and socio-economic-impacts, related to food-wastage-disposal.

There are four-broad-approaches to food-wastage-reduction: (1) improve food-security; (2) improve food-safety; (3) reduce wasted-resources; and (4) increase-profits along the food-supply-chain (Sheahan & Barrett, 2017).

In-particular, FAO (2013) highlighted the-following-approaches to food-waste-reduction: Promoting food-wastage-audits; Improving-communication, along the-supply-chain, to-match demand and supply of food; Improving organization within-institutions; Improving-communication between the different-stakeholders in-the-supply-chain; Developing improved-food-harvest, storage, processing, transportation, and retailing Processes; Improving harvest-techniques and post-harvest storage; Improving processing-techniques; Improving packaging; Improving transportation; Improving retailing; Improving quantity-planning for food-services; Improving consumption-habits; and Revising regulation on-aesthetic- requirements for fruit and vegetables.

Food-waste-recovery can generally be defined as the-collecting and reusing food-scraps, through donation of edible-food to charities, and the-recycling of edible-food, through composting, and other-end- uses (CIWMB, 2006). Food-recovery-programs are conducted in-many-institutions, for-example: University of Maryland, Pomona, UC-Berkeley, Harvard-University, Columbia-University, University of Chicago, Princeton-University, and Stanford-University, among-others (Dickinson, 2014). **Figure 3:** shows Food Waste Recovery/Management approaches.

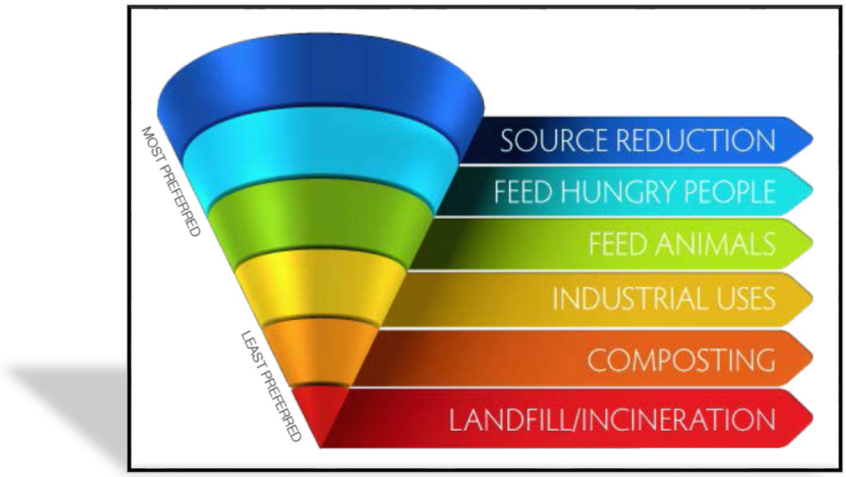

Figure 3: Food Waste Recovery/Management (FWRA, 2014).

The-next-sections will provide some-details on each of the-approaches, alongside-with assessing their-applicability in the-local-context.

3.2.1. Source Reduction.

The-FAO (2011) estimated that global *consumer* food-waste constitutes 35% of the-overall-food-wastage. In-the-same-accord, Bond *et al.* (2013); USDA (2011); and Engström & Carlsson-Kanyama (2004) stated, that the-amount of food-waste, generated from the-hospitality-sector is too-big to-be-ignored. Due to this-great-magnitude, reduction of consumer-food-waste has been-accorded the-highest-priority in the-general-fight against food-losses and wastes (FAO, 2013).

Food-waste in food-service-institutions can be-broadly-categorized as: (a) *Kitchen waste* – which includes wastes, occurring during-food-storage, ingredient-preparation, cooking, and serving (Engstrom & Carlsson-Kanyama, 2004). Elsewhere, kitchen-wastes are referred-to-as pre-consumer-waste (LeanPath, 2012). Kitchen-waste also includes foods, prepared *but* never-served, and eventually-discarded i.e., leftovers (Youngs *et al.,* 1983); and (b) *Plate waste* – which is food that is served, but left uneaten and discarded. LeanPath (2012) refers to plate-waste as post-consumer food-waste or ‘table-scraps’.

Wherever-possible, the-distinction is made among three-classifications of consumer-food-waste (see **Figure 4**) as: ‘avoidable’, ‘possibly-avoidable’, and ‘unavoidable’.

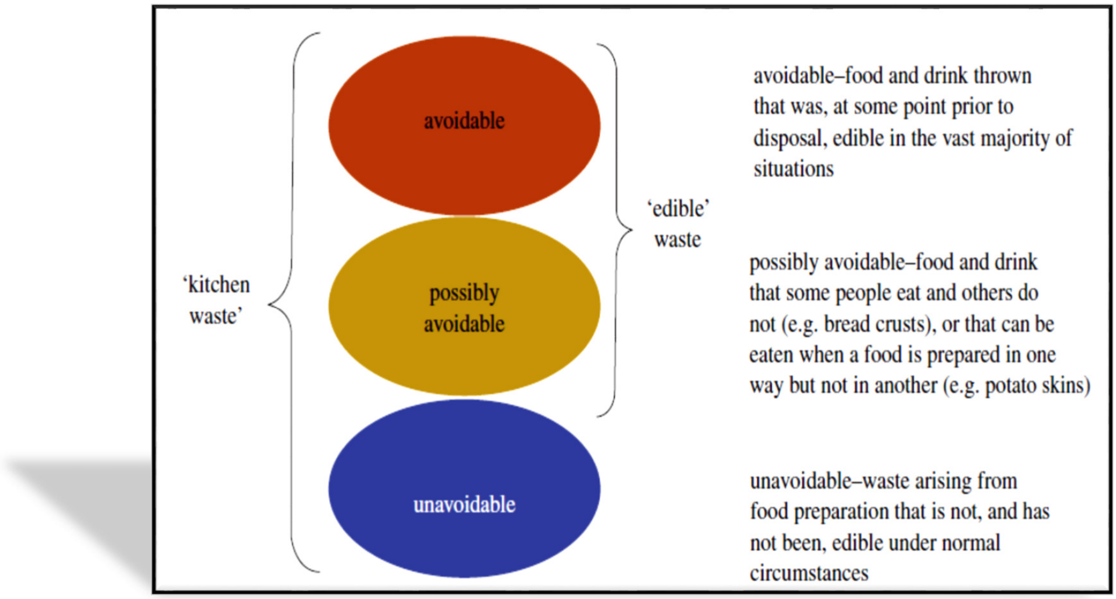

Figure 4: Definitions associated with household-food and drink waste (WRAP, 2009a).

From a-study by the-WRAP (2009a), avoidable ('too much food is cooked, prepared or served') constitutes 64% of the-total food-waste; possibly-avoidable (food *only*, which is *not* used in-time) - 18%; and unavoidable - 18%.

WRAP (2011) also-states that the-causes of food-waste, in-food-service-institutions, can be-broadly classified-into three-main-categories: operational, situational, and behavioral. The-results of research, carried-out in-Great-Britain (WRAP, 2008) identify the-two principal-causes of *avoidable* household-food-waste: (i) Too-much-food is cooked, prepared, and served, thus producing so-called 'leftovers', which include foods 'damaged' during-cooking (e.g., burned-food); and (ii) Food is *not* consumed, in-time: food and beverages are 'thrown-away' because they exceeded the-expiration-date, stated on the-package, deteriorated, or *no* longer seem to-be-edible. For waste, generated in-the-catering- sector (such-as in hotels, restaurants, and cafeterias), the-causes of waste are more or less the-same, *but* have even-more significant-effects: the-excessive-size of food-portions, served which, in-part, are left on the-plate; difficulty in planning food-purchases, which is further-complicated, in-the-case of buffet-service (buffets usually involve preparation of a-larger-amount of food, than is necessary); and lack of acceptance of practices, allowing customers to-take home their 'leftovers'.

Reducing food 'plate waste' is a-complex-phenomenon, which requires a-multifaceted-approach, which involves sequential-trial and appraisal of potentially-effective-approaches. These-approaches include: Implementing 'offer-versus-serve' food-serving-option (Buzby & Guthrie, 2002); Offer different- portion-sizes (Noleppa, 2012); Convenient time-scheduling (Bergman *et al.,* 2004; Getlinger *et al.,* 1996); Improving food-quality and acceptability (Buzby & Guthrie, 2002; US-GAO, 1996; Hartwell *et al.,* 2006; Liquori *et al.,* 1998); Reducing the-size of eating-bowls (Wansink *et al.,* 2013); Engaging students in food-waste minimization-strategies (Engström & Carlsson-Kanyama, 2004); Using appropriate-food pricing-system (Engström & Carlsson-Kanyama, 2004); Employing appropriate-food-menus to-reduce plate-waste (Williams & Walton, 2011; Sonnino & McWilliam, 2011; Díaz & García, 2013); Appropriate meal service-system (Williams & Walton, 2011; Puckett, 2004; Engström & Carlsson- Kanyama, 2004; Wilson *et al.,* 2000; Kelly, 1999); Food-plate waste-auditing (Díaz & García, 2013; Gunders, 2012; LeanPath, 2012; Nichols *et al.,* 2002; Kantor *et al.,* 1997); Consumer-education (Whitehair *et al.,* 2013; Paul & Rana, 2012; Freedman, 2011; Griffin *et al.,* 2009; Petersen *et al.,* 2007; Kantor *et al.,* 1994); and Appropriate-communication (Zhang *et al.,* 2011; Kelly *et al.,* 2006).

On-the-other-hand, according to FAO (2011):

> Poverty and limited household income make it unacceptable to waste food. A contributing factor is that consumers in developing countries generally buy smaller amounts of food products at the time, often just enough for meals on the day of purchase.

Kenya is a-developing-country, where according-to FAO (above-statement), wasting food would be unacceptable. High-share of food-waste (37%) in the-total-waste, in the-university, could be contributed by the-fact, that the-meals are sold, to-the-students, at very-low/subsidized-prices; low-price and high- availability of food might-cause a-decline of the non-economic (environmental, ethical, social) value of food. Students largely-behave as they do *not* value food, whatsoever (by taking large-portions and discarding most of the-food), provided to them, at the-canteens and eateries. This-situation calls for a-behavioral-change, at the-university.

Due-to the-nature of large, institutional-dining-operations, more-action can be taken to-reduce food-waste, through an-initiative to-raise-awareness about food-waste and its-consequences. Prendergrast (2008) pointed-out on the-factors driving to-behavioral-change, which can-be classified in three-areas: (i) external-factors (financial and efforts-costs); (ii) internal-factors (habits and cognitive-processes); and (iii) social-factors (societal-norms and cultural-attitudes). A better-understanding of the-negative-externalities of food-losses and wastes can-lead-to the-reduction of behaviors, that takes to the-creation of a-higher- amount of waste (WRAP, 2007b). While attempts to-shift consumer-behavior *may* result in-reduction in-food-waste, changes in-legislation and business-behavior, towards more-sustainable food-production and consumption, will-be-necessary, to-reduce waste from its-current-high-levels (WEF, 2010).

According-to Ochieng' (2015): "Due to its complexity and intricacy, complete elimination of food waste in foodservice is not achievable". To-reduce the-food-waste, deeper-understanding on the-reasons, behind such-behavioral-practices, is paramount. There is a-limited-number of studies, focusing-specifically on the-reasons, for wasting food, largely-restricted-to the-UK (WRAP 2008; 2009 a; 2009 b; Lyndhurst, 2007; Exodus, 2006); the-USA (Van Garde & Woodburn, 1987); and Australia (Hamilton *et al.,* 2005), while *no* study was traced in the-Kenyan-context. This-study, hence, recommends further-research on the-reasons for food-waste, at the-institution.

3.2. 2. Feed Hungry People.

Gunders (2012) describes food-recovery, as the-act of garnering excess or edible-food, and distributing it to-those, who-need-it. The-process entails gathering perishable, non-perishable, and already-cooked food-items, from the-various-actors, along the-food-supply-chain. Recovered-food is then handed-over to food-donation-systems, for-example food-banks, which in-turn redistribute it to-people with-limited-access to-food (RSIS, 2013; Griffin *et al.,* 2009). Even in-affluent-countries such-as the USA, poverty and hunger are realities (EPA, 2014).

For-example, US-EPA (2015) has identified the-two-largest food-donation-organizations are: Feeding-America (FA), and Food-Donation-Connection (FDC). *FA* comprises over 200 food-banks, across the-U.S.A., and supplies more-than 1.5 million-tons of food, annually, to-those, in-need. However, this includes food, generated-specifically for donation (i.e., non-waste), as-well-as food, from the- manufacturing and agricultural-sectors. Among other-programs, FA runs a Retail-Store-Donation (RSD) - program, which coordinates the-donation of surplus-food, from over 10,500 grocery-stores. In-2012, around 450,000 tons of food-waste was donated through the FA's RSD program. *FDC* consists of around 250 food-service-entities and restaurants, and coordinates the-donation of surplus-food from restaurants (food that would otherwise be handled through the-solid-waste management-system). In-2012, 18,000 tons of food-waste was donated through FDC-programs. As-such, food-collection and redistribution can play a-significant-role in-improving food-security (Griffin *et al.,* 2009; Kantor *et al.,* 1997). However, liability- concerns (due-to possible food-waste-contamination), and transportation-limitations, are the-most commonly-noted-barriers to food-donation. Specifically, transportation-costs, lack of refrigerated-trucks and drivers, and chain of custody-issues, in-case of recall, were noted.

Besides, from an-ethical and social-perspective, considering the-high and rising-numbers of hungry-people in-both; developed and developing countries, food-recovery is seems as an-excellent-option. However, food-recovery and redistribution is also a-contentious issue. Firstly, aspects such-as: food- hygiene or quality, and the-possible-health-consequences of consuming recovered-food have hampered recovery-efforts (RSIS, 2013; Engström and Carlsson-Kanyama, 2004). Food-cross-contamination can involve pathogens such-as *Escherichia coli, Salmonella, or Campylobacter* (Marklinder *et al.,* 2013), making such-food unsafe and even-deadly, if consumed. At-times, spoilage or contamination is *not* even-perceptible to the-human-senses, and goes undetected, leading-to adverse-health-effects, when food is consumed. Several well-publicized-outbreaks of acute-aflatoxicosis in-Africa – including the-death of 125 Kenyans, in-2004 – suggest undetected-food-spoilage, with very-severe human-health-implications. Mycotoxins, in the-forms of fumonisin and aflatoxins, can lead to slow-developing esophageal and liver-cancers (respectively), and are growth retarding and immunosuppressive, even in-small-doses. These-food-safety-concerns, arising-from fungal or pest-infestations, have major-disease and global-health- implications. Moreover, Mutiga *et al.* (2015), among others, suggest that fumonisin, aflatoxin, and other-mycotoxins-contamination are more-widespread than previously-appreciated.

Furthermore, recovery, conversion, and redistribution of 'lost' food into-food, fit for human- consumption, can-be-costly and, sometimes, difficult (Gunders, 2012). Locating food-donors, securing paid-labor or volunteers, training workers on safety-measures, during-food-handling, and securing funds for establishing infrastructure for storage, packaging, and transporting of the-donated-foods, all require significant-commitment, from both; public and private-sectors (Kantor *et al.,* 1997).

Possible-serious-food-contamination, and current-lack of legislation to lower-food-wastage and guidance on the-process, itself (see Starovoytova, 2018a; 2018b), alongside-with the-fact that food-banks are *yet* to-be-created, in-Kenya, and moreover in-Eldoret, food-recovery-option is considered as *not* yet practicable.

3.2.3. Feed Animals.

Feeding food-waste to-livestock has been-practiced, throughout the-world, for a-long-time, mostly in-urban-farming (Harris *et al*., 2001; Westendorf *et al*., 1998; Derr *et al*., 1988). Depending on the-product and the-relevant-local-regulation, food-waste can be fed directly to-animals, either slightly (sterilized), or heavily (dehydrated) processed (FAO, 2013). Using food-waste as livestock-feed has the-potential to-create revenue and jobs. For-example, in-countries, such-as, Japan and South-Korea, businesses have been established to-collect and process food-waste and sell it to-farmers (Stuart, 2009).

The-environmental and economic-benefits of feeding food-waste to-livestock seem striking. For-example, a-study, performed in-New-Jersey, U.S.A. compared growth, meat-quality, and diet-digestibility, when pigs were fed left-over food, from a-cafeteria, or a-corn/soya meal-diet. The-result shows that leftover-foods have good-nutritionally-quality, digestibility, and protein-availability (Frendberg, 2012). Besides, the-Swine-Health-Protection-Act of 1980 (SHPA) legally protects both; consumers and pigs. This-act requires that food-waste, containing meat, should-be heat-treated, before it-is fed to-pigs. This helps prevent disease, like Hog-cholera, Foot and mouth-disease, African-swine-fever, and Swine vesicular-disease, and pathogens, like salmonella, campylobacter, trichinella, and toxoplasma, which could- spread to-other-animals, including humans. The SHPA-required heat-treatment is done, through either; the-direct fire-method, or the-steam injection-method. In-the-direct fire-method, the-food-waste is placed in a-cooking-vat, which comes in-direct-contact with flames. In the-steam-injection method, steam is inserted-into the-bottom of a-pile of food-waste and evenly-heats the-waste, as it percolates-through**.** The- SHPA, however, does *not* require food-waste, *without* meat, to-be-cooked.

The-practice of swill-feeding, actually, came to an-abrupt-end in-2001, when the-UK-government concluded that the-catastrophic Foot-and-mouth disease (Bovine Spongiform Encephalopathy – BSE) outbreak, originated on a-farm, which was feeding swill to-pigs. The-UK-government decided to-ban swill-feeding and adopted the-Animal by-Products-Amendment (England) Order in-2001. It did *not* take-long for other-national-authorities, to-implement similar-measures, and prohibitions on the-use of animal-byproducts as feedstuff, were set also in the-EU; USA (state of Texas); Australia; and New-Zealand (Waarts *et al.* 2011).

Nevertheless, according-to Practical-action (2001), the-pig-farmers will continue the-use of food-waste as pig-feed, since this is the-most-economic-feed. A-cost-comparison, shows that profit is more-than-doubled, by feeding the-pigs-on organic-waste, even when including all-other-costs, such-as cost of vet-nary-treatment, transport, fuel, etc. In-addition, department of Agricultural-Production, at Makerere- University, Uganda, shows that the pig-farmers' observe the-following-impacts, when using left-over food, as pig-feed (Frendberg, 2012): (i) it gives an-opportunity to a-higher-feed-intake; (ii) good-growth- performance and improved-body-condition; (iii) good-reproductive-performance, measured as timely-estrus, large-litters, and piglets with good-body-weight, at birth; (iv) fair-ability to-produce lean-carcasses (less-fatty-pork); and (v) improve the-sows milk-production, for piglets, during-lactation.

On-the-other-hand, Westendorf *et al*. (1998), reported that pigs, fed with leftover-food grew more-slowly, and had a-lower slaughter-weight, compared to-pigs, fed the-corn/soya meal-diet. In-addition, a-review for Kenya's pig-sector, developed in-collaboration-with FAO-ECTAD, describe that the-drawbacks, when using leftover-food as pig-feed, are that the-safety, amount, and quality of feed, is *not* guaranteed, and pigs fed inadequate and unbalanced-diets will have low-weight-gains (FAO, 2012). Besides, a-study in-Kampala, Uganda identified a-notable-amount of physical-contamination and bones, in leftover-food, used as pig-feed. The-physical-contamination includes hard and sharp-edged-materials, that can harm pigs' digestive-system, and furthermore it contains bones, which can spread serious-diseases, such-as Swine-fever, Porcine-Reproductive-Respiratory-Syndrome (PRRS), and salmonella, if pig-feed contain pork-bone (cannibalism), and meat, from other-animal-sources. In-addition, high-levels of potentially-harmful indigestible-plastic and metal-contaminants were observed in food-waste. Moreover, metal may contain heavy-metals, which affect the-pork-quality, as it can be accumulated/stored in-pig- muscles, and become a-health-risk for the-meat-consumer (Frendberg, 2012).

Food-waste feeding-to-animals-option has-been-practiced, in-the-university (to a-limited-extent), where nearby-farmers (mainly pig-farmers, and to a-lesser-degree, chicken-farmers and dog-owners) use their-transport, time, and their-containers, to-buy/collect, the-food-waste, from the-university-eateries, on a-daily-basis. Reported-barriers to recycling food-waste, as-animal-feed, include transportation-constraints; costs to-separate food-waste, from packaging; cost of purchase; and concerns about the-safety of some-type of food, for animal-consumption (for-example, some-food-scraps, such-as coffee or foods, with high-salt content, can be-harmful to-animals); *no* concerns about food-transmitted-diseases were, however, raised.

Turning food-waste into animal-feed comes with challenges, but it also provides overwhelming- benefits, in-this-regard, this-study-recommends, for the-food-waste to-be-used as-animal-feed, it should be: (i) first, sorted-out, of any-physical-contamination (to-remove all indigestible-components, such-as plastics, glass, bones, metal, any-sharp-objects, etc.), and then (ii) thermally-treated, to-avoid serious-food transmitted-diseases to-both; pigs, and humans. These-operations will probably-result in a-higher-price, for food-waste, *but* a-better-quality-feed can be obtained.

3.2.4. Industrial Users.

The-waste-management-hierarchy is one of the-guiding-principles of the-zero-waste-practice (see Starovoytova 2018a; 2018b). By-analogy-with this-principle, the-development of green-production processes can be-achieved, following the short, medium, and long-term-goals (Laufenberg *et al.,* 2003), such-as: (1) *Short-term-goals* involve waste-minimization, by reduction and recycling of valuable- substances, by-products, and residues, with reduction of emission, and risk, as a-final-outcome; (2) *Medium-term-goals* include development of efficient-production-process, adding-value to by-products. The-outcome, for the-companies, is their higher-environmental-responsibility, accompanied by competitive advantages; and (3) *Long-term-goals* consist of step-by-step-implementation of environmentally-friendly- manufacturing, developing 'innovative-products'. The-ultimate-outcome is design of innovative-food- products, such-as functional-foods, which can open new-markets, and meet green-productivity-objectives.

According-to Waldron *et al.* (2004), the 'Total-food' Conference highlighted new-developments, aimed to-exploit the-entire-quantity of food-resources, rather than the-final-portion-consumed, facilitating transfer of knowledge, among agro-food-industry-stakeholders. The-Conference-Proceedings present several-studies, focused on: waste-minimization, water and energy-recovery, during food-processing, added-value-by-products, from vegetable and dairy-food-chain, exploitation of invaluable-residues, to-produce bio-fuel, and food-safety-concerns. With particular-interest, to-this-study is potatoes and tomatoes, as they are consumed on a-daily-basis, and also, on-observations, they found to-constitute a-markedly-substantial-share in the-food-waste, from the-catering-facilities, as-well-as from the-stage- market, of the-university. The-next-sections, hence, provide some-details.

Potatoes are one of the-most-commonly consumed-vegetables, throughout the-world. Potatoes mainly-contain carbohydrates, especially starch, vitamins, minerals, and phytochemicals, such-as carotenoids and natural-phenols. Peels are the-major by-product of potato-processing-industries, and contain the-same-amount of valuable-compounds of edible-vegetable. Results of a-research by Farvin *et al.* (2012), suggested that ethanol-extracts, of potato-peel, can be-employed as-natural-antioxidant. Kanatt *et al.* (2005) reported that potato-peel-extracts retard lipid-peroxidation of radiation-processed-meat, without affecting its-flavor. Nelson (2010) proposed to-use by-products of potatoes-industry-processing as-cattle feed. Okuno *et al.* (2002) utilized supercritical-carbon-dioxide (SC-CO_2) extraction to-waste-powder, derived from sweet-potatoes-roots, highlighting the-possibility of extracting antioxidants from waste- materials with SC-CO_2. Furthermore, the-compounds extracted, have *no* toxic-solvent-residue, as this- extraction does *not* require organic-solvents, and it-is itself *nontoxic*.

Tomato is the-second most-important vegetable-crop, after potato, worldwide, with annual- production at 100 million-tons fresh-fruit produced, in 144 countries (Kalogeropoulos *et al.,* 2012). Tomatoes are rich in-bioactive and valuable-compounds, such-as: carotenoids, mainly lycopene (80-90%), b-carotene, vitamin C, vitamin E, and various-phenolic-compounds. Studies by Kalogeropoulos *et al.* (2012); Ćetkovi *et al.* (2012); Herrera *et al.* (2010); and Dumas *et al.* (2003), showed that industrial-tomato byproducts contain significant-amounts of bioactive-phyto-chemicals, known to-exert antioxidant-activities. Therefore, these value-adding-constituents could-be either; isolated from the-wastes, to-be-used as natural-antioxidants, for the-formulation of functional-foods, or to-serve as-additives, in-food systems, to-elongate their-shelf-life. Besides, Machmudah *et al.* (2012); and Ishida & Chapman (2009) confirmed that ethyl-lactate is an-excellent-solvent, to-extract carotenoids.

For-more-information, on recovering of added-value-products from FW (Upgrading Concept), refer-to Kosseva (2011).

Besides, according-to California Department of Resources Recycling and Recovery, food-wastes composed of animal by-products, fats, and oils, can-be-rendered into saleable-commodities, such-as: high-protein-tallow, or grease, which are used in the-production of animal-feed, soap, paints, and varnishes, cosmetics, explosives, toothpaste, pharmaceuticals, leather, textiles, lubricants, bio-fuels, and other valuable products. In-addition, the-valorization of catering-waste focuses on the-utilization of used- cooking-oil in non-feed/technical-applications, such-as its-conversion-into bio-fuels and other-products (Gale, 2002). It-is-important to-note, however, that in-order-to-promote an-industrial-symbiosis, among-companies, feasibility-studies is essential, to-further-classify the-type and amount, of food-wastes, and to-identify, which industrial-sector/activity might transform and use such-food-wastes.

3.2. 5. Composting.

It-is-appropriate to-mention-here (at the-beginning of discussion on composting) a-common-misconception -- some-people say: "organic food waste isn't really bad for the environment as it goes back to the soil". According-to FAO (2013), this-statement, however, is wrong for several-reasons: unless compost is created from-waste, *no* part of the-waste goes back to-the-soil, all of the-natural-resources, used to-create the-food are definitely wasted, and even if it-is organic, any-food-waste-decomposition has a-very-high methane- emission-rates.

Composting is an-economic-way of reducing greenhouse-gas-emissions, while simultaneously- recycling soil-nutrients (RSIS, 2013). For food-service-operators, regular-composting can result in significant-money and energy-savings, due-to reduced-transportation of solid-wastes to the-landfills (Griffin *et al.,* 2009; Stuart, 2009). Furthermore, composts act as biological-suppressers of soil-borne plant-pathogens, notably fungi. Thus, composts are an-alternative-to chemical-control of soil-pathogens. While the-use of chemicals is the-most-efficient-method to-control-pathogens, chemicals have been associated with atmospheric-pollution and evolution of chemical-resistant-pathogens (Vossen *et al.,* 1999).

Composting, in-essence, is the-acceleration of the-natural-process of decay of biodegradable- matter, done by various micro-organisms, including: bacteria, fungi, and actinomycetes. Composting can be conducted aerobically or anaerobically, under-conditions of temperature and moisture, suitable for acting- micro-organisms to-thrive (Wilson, 2009). Aerobic-process was chosen, for further-considerations, due-to various-reasons, such-as: (i) it-is fast, since the-microorganisms in-it, consume and decompose the-organic-matter, quickly and more-efficiently, than the-anaerobic-one; (ii) it works in an-aboveground- environment and requires *no* digging into-the-soil; and (iii) it-is cheaper, than anaerobic-system.

Aerobic-composting is an-aerobic bi-oxidative-process, in-which microorganisms, break-down raw-feed-stocks, to-produce a-stable organic-material, containing nutrients, essential for plant-growth (Clark, 2000). Composting, therefore, can offer linked-economic-opportunities in-agriculture and landscaping (David, 2012). Composting also-includes a-thermo-philic-phase, during-which *not* only organic-matter-degradation occurs, but pathogens are also effectively-reduced (Tognetti *et al.,* 2005), resulting in a-nutrient-rich-humus/compost.

The-following organic-waste can be-accepted at small-scale, low-tech composting-facilities (ISWA, 2016): (i) Putrescible organic-waste (high in Nitrogen-concentration, high-moisture-content, low-permeability to-air); (ii) Food-waste (from catering-services, households, and markets); (iii) Lignin/ cellulose-based organic-waste (with high-Carbon-concentration, low-moisture-content, high-permeability to-air); (iv) Yard-waste (e.g., grass, tree, and shrub pruning, flowers etc.); (v) Wood (solid or chippings); (vi) Saw-dust/shavings (untreated-wood only); and (vii) Paper, cardboard, and other-compostable-packaging (e.g., wood-fibre, cotton-fibre, jute-fibre).

Pre-treatments, as-well-as post-treatments, are required, in-order-to-produce high-quality-compost. Several-mechanical-pre-treatments, aimed at 'conditioning' the-physical-nature of waste to-be-biologically processed, should be conducted, such-as: (a) Shredding/de-fibering lignin-based woody-organic-waste; (b) Opening bags, containing the-putrescible organic-waste-fraction; (c) Mixing/homogenizing different-types of organic-waste; and (d) Drying/moistening the-starting-mixture. It-is-important to-note, that only bulky non-compostable-material, shall be-manually-removed, at this-stage. Post-treatments are aimed at removing non-compostable and sorting bulking-woody-fractions by: Screening by size, in-order-to-recover large-sized woody-materials, to-be re-circulated in the-starting-mixture; and manually sorting-out from the-over-screen- fraction undesired-materials, such-as: plastics or metals (ISWA, 2016).

Aerobic Processing Technologies include: (i) Passively-Aerated and Turned-Composting-Systems (Static Pile-Composting; Bunker; Windrow; Turned-Mass-Bed; and Passively-Aerated-Windrow); and (ii) Actively-Aerated-Composting-Systems (Aerated-Static-Pile; Enclosed-Aerated Static-Pile (Tunnel); Static Container; Agitated-Container; Channel; Agitated-Bed; and Rotating-Drum). For more-details, on each of the-listed-systems, refer to Environment-Canada (2013).

Composting have been also-practiced in several-universities, for-example: (i) Pepperdine- University sends 22% of its-waste to-landfills, and recycles the-remaining 78%, while all-garden-waste and food-waste is composted to-produce fertilizers; (ii) American-University is a 100% free-waste-university. They compost all the-food-waste and paper-towels, and recycle kitchen-grease for electricity; (iii) College of Atlantic has recycling-outlets for bottles, cans, glass, and paper. Also, food-waste and napkins are used for composting; (iv) University of California-Davis recycle 120 tons of items, and 98% of its-food-waste has-been-composted, since 2009. This-university launched a-program, called the-Bucket-Program, where students collect food-waste in-their-rooms. And in-2007, the-university introduced the-USA first zero-waste athletic-stadium; (v) Harvard-University joined the-compost-movement, in 2011, and reached a-decrease of 103 tons of food-waste, sent to-the-landfills; (vi) Purdue-University, which follows the 'recycle first, trash later' slogan, and composts animal-waste and had-reduced trash-pickup to-twice a-week; and (vii) Ohio University becomes, in-2009, the-university with the-largest (2 ton) in-vessel compost-facility in the-U.S.A. *No* records, however, were traced, on the-formal-use of composting, at Kenyan-universities.

The-next-section is focused on the-design of small-scale-composter of aerobic-category and of Rotating-Drum-type.

3.3. Design of the-composter.

Selected relevant-International-patents (developed by individuals, as-well-as design-companies) were reviewed; examples included: US10030279 (2018); US20150031122 (2015); US20140349384 (2014); US8889407 (2014); US8871501 (2014); US20140242686 (2014); US20130183748 (2013); US7091036 (2006); US5457031 (1995); USD352580 (1994); and US3837810 (1974). The-listed-patents were picked to-attempt to-cover the-various-shapes for composter-design: spherical, rectangular, and cylindrical-shapes (see **Figure 5**).

Besides, the-previous-work of selected-authors, who designed aerobic-composting-systems were analyzed, including: Jayaprakash *et al.* (2018); Toumi (2017); Dong *et al.* (2014); Christiana (2014); Ojumu & Opafunso (2012); Wilson (2009); Smith *et al.,* 2006; Petiot & Guardia, 2004; Chelecha (2003); Nakasaki & Ohtaki, 2002; Glanville (2001); and Rynk & Col (1997). The-review of the-listed-composter-designs identified, that all of them have few-limitations, like: high-investment, and operating-costs (Bohn *et al.,* 2007), and in-addition, these-designs exclude small-scale-composters. The-design by Rynk & Col (1997) was chosen as a-point of reference, due to its-relative-simplicity and affordability.

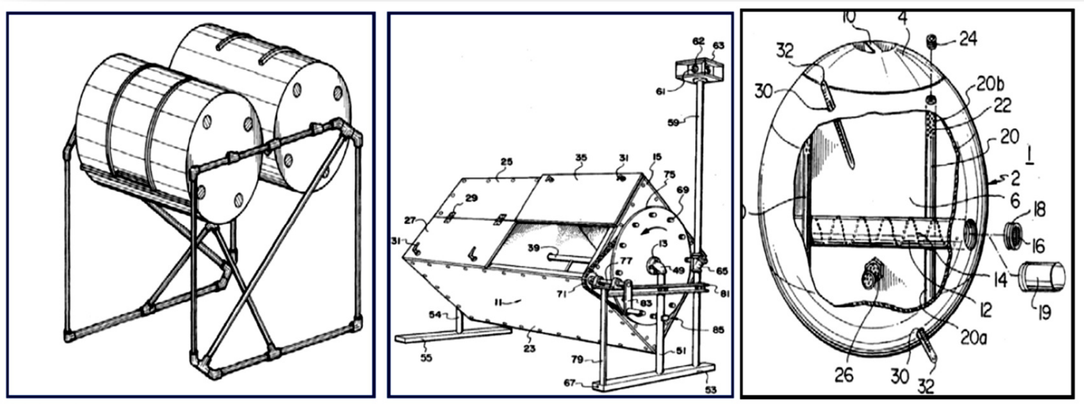

Figure 5: Examples of different-composter-shapes developed and described in-the-patents: USD352580 (left); US3837810 (middle); and US5457031 (right).

Composters are available in very-different-shapes; examples are presented in **Figure 5.** The- rotating drum/tumbler kind of composter was chosen, due-to the-turning-action it provides, to-aerate the-waste, providing the-microorganisms, present, with needed-oxygen. Moreover, this-study is focused on *cylindrical* rotating-drum-type composter. Additionally, putting the-compost in a-closed container is better, for the-local climatic-conditions, where it rains, for long-periods of time. Rotating-drums (or wet-pulverizes) mix materials, by tumbling them, in a-rotating-cylinder. Internal flights/vanes/ blades lift the-waste-material up-the-sides, of the-drum, where they fall to-the-base. Drums take-advantage-of gravity to-tumble, mix, and homogenize the-wastes. Homogenization is particularly-important, if mixing is limited in-the- subsequent-composting-system. The-residence-times, of less-than 36 hours, allow *only* the-beginnings of microbial-decomposition (Richard, 1992; Vastola & Pizzo, 1987).

On-the-other-hand, a-key-strategy in the-PDP *(Product Development Process)* is to-avert-failure of a-machine, or structure, by predicting and analyzing potential-failure-scenarios, at the-design-stage, *before* the-machine is built (Budynas-Nisbet, 2008). By identifying the-loads, the-governing-failure-modes and tentatively-selecting the-appropriate-candidate-material, the-failure-prediction-scenarios provide a-basis for choosing the-optimal-combination of design-parameters: geometry, materials, and loads. Factor of safety (FoS), also known as (and used interchangeably-with) safety-factor (SF), and design-factor of safety (N), is a-term, describing the-capacity of a-system beyond the-expected-loads, or actual-loads. Essentially, the-factor of safety is how-much-stronger the-system is, than it usually needs to-be for an-intended-load.

Factor of safety is also-depends on the-intended end-use of the-product. For-example, Equipment Factor of Safety (FOS) for: Aircraft-components is between 1.5 and 2.5; Boilers (3.5 - 6); Bolts 8.5; Cast-iron-wheels - 20; Engine-components (6 - 8); Heavy-duty-shafting (10 - 12); Lifting equipment-hooks (8 - 9); Pressure-vessels (3.5 -6); Turbine-components-static (6 - 8); Turbine-components-rotating (2 - 3); Spring, large-heavy-duty - 4.5; Structural-steelwork in-buildings (4 - 6); Structural-steelwork, in-bridges (5 - 7); and Wire-ropes (8 - 9) (Iorga *et.al.,* 2012; EngineeringToolbox, 2016). FoS of 8 was used, in-this-design.

Three-alternative-designs were hand-sketched. In-selecting the-best-design, weighted-attributes, reflecting their-importance, was chosen as-follows: Eco-green design-aspects 0.3; Ease of fabrication and assembly@ 0.2; and Occupational-Safety & Health @0.2; while Ease of operation, and Efficiency @0.1 each. Alternative-design # 1 was selected with the-highest-score of 0. 81.

The-main-material, chosen for the-composter is *mild-steel*; it has the-following-properties: Density of 7.85 gm/cm^3; Young's modulus of 210 MPa. Carbon-atoms, affixed in the-interstitial-sites of the-iron lattice, and make it stronger and stiffer; however, the-strength comes at a-price of decrease in-ductility of the-alloy.

The-designed small-scale, low-tech, horizontal, rotating-drum-composter consists of a-mild-steel- drum, mounted directly on the-frame, for stability. The-drum is of a-diameter of 1.2 m, length of 3.9m, and internal-design-capacity of 15m^3 (the-drums are usually loaded to between 65-80% of their-design- capacity/total-volume, to-allow aeration).

The-composter has the-following-components: (i) Two-cylinders (inner and outer cylinder); (ii) A-ball-bearing, in-between the-two-cylinders, to-allow for easy-rotation of the-inner-cylinder; (iii) A-frame, to-support the-composter; (iv) A-shaft, to-transmit the-motion, when the-drum is rotated; (v) Blades, inside the-inner-cylinder, to-beat-up the-compost, when the-drum is rotated; (vi) Two-meshes on the-inner-surface, to-filter in-the-compost-materials; (vii) A-handle, to-facilitate rotation; (viii) A-tap to-drain the-waste-water, collected from the-filtration-process; and (ix) A-hinged-opening/discharge-door, for loading and off-loading the-compost. This-process can be-easily-performed, without a-mandatory agricultural-experience. The-design can be scaled; as-long-as the-critical-parameters of the-process are satisfied.

The-drum is mounted directly on a-frame, and is positioned on a-slight-incline of 2^0, and it-is rotatable, manually, with a-help of a-handle. A 20mm-diameter cylindrical-metal-shaft/pipe, passing through the-center, of the-composting-drum, horizontally, spans through the-length of the-composting-drum inside. 9 metallic slightly-sharp-blades, of a-length of 37cm, each, have been-welded-to the-shaft (see **Figure 6** in-red), enabling air-circulation, on rotation. Additionally, 10 holes, of a-diameter of 2cm each, were punctured, on the-upper-area of the-composter-drum. Also, the-composter contains a-door, which allows some-air entrance, even when closed. The-combination of the-drum's rotation and incline, blades, with gravity, results in-waste-materials, being-well-mixed, and aerated. This-composter is designed with a-short composting-time of one to seven-days, hence the-compost, needs further-treatment.

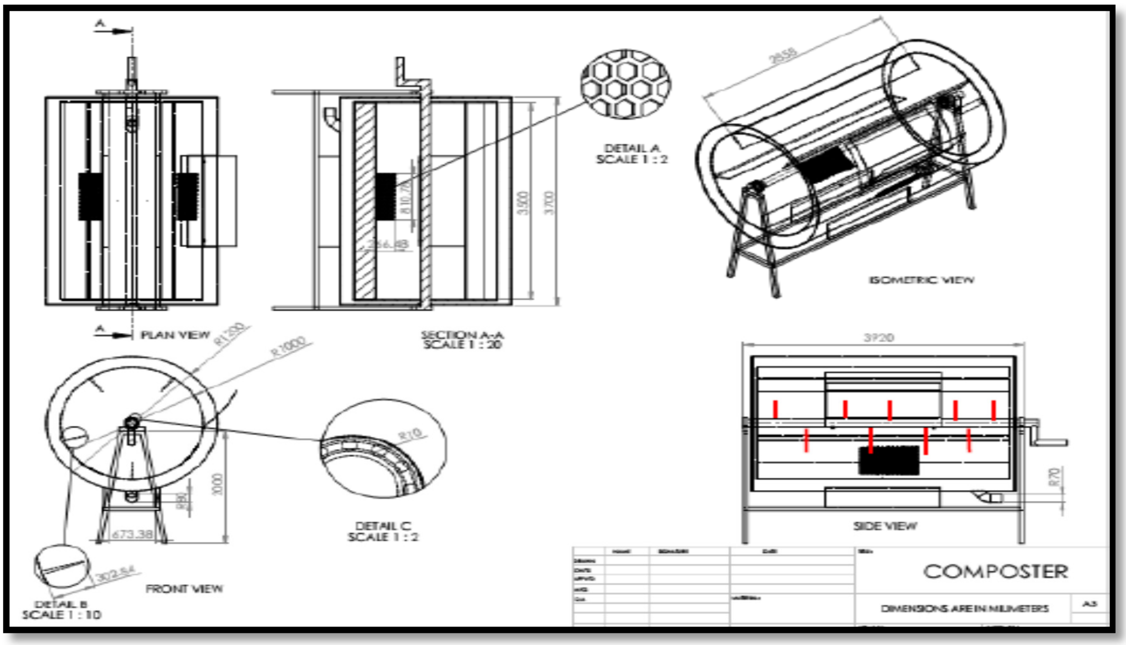

Figure 6: Designed-composter

This-design is largely-preliminary; next-logical-step, would be a-detailed-design, which can-be generated, using 3D-solid-modeling CAD-programs, such-as SolidWorks. Besides, the-Finite-Element Analysis/Method (FEA/FEM) can-be used, to-conduct stress-strain-investigations. To-eliminate/reduce 'overdesigning', and to-obtain sequential-solutions, that exhibit asymptotic-convergence to-values, representing the-exact-solution, it-is recommended to-conduct *refinement* of the-mesh in-FEA. In-addition, AUTODESK Simulation-Mechanical, can-be used, to-perform stress-strain-analyses and heat-transfer-modeling. Moreover, final-trade-off of performances-test (see Masctelli, 2000), and FMEA-tests should-be conducted, as every-product has some-possible failure-point, and it-is-important to-identify such-failure point(s) and the-subsequent-effect (s). A-particular-component-failure is often identified, during the-use-ability testing-process, meaning that *only* that-component should-be redesigned, and *not* the-entire-product.

4. Closing remarks: Values of and Respect towards food.

At a-global-level, there is a-valid-argument that it-is morally-unacceptable that, in-a-world, where so-many-people go-to-bed hungry, so-much-food is lost and wasted (Mena *et al.,* 2011). At a-local-context, the-study identified high-food-waste-share in the-total-waste, of the-university, and contributing to it, behavioral-disrespectful-practices towards food, demonstrated by many-students, in-the-campus.

Hudson & Messa (2015), in their-position-paper on Food-losses and Waste, concluded, that food-wastage can be fought at its-root *only* by restoring value to food. They also pointed-out, that:

> Treating food as a-mere-commodity implies stripping it of its-social and cultural-value. Food production and food consumption have deep cultural roots: we grow and eat food so as to survive and live, but also to celebrate important events, define our identity and not least, for pleasure. Food is inextricably linked to our cultures, to our individual and collective histories, and to our identity. It embeds precious knowledge, from the fields to the kitchen, passed on through the centuries.

In-the-same-accord, *Anthony Bourdain* said:

(https://www.brainyquote.com/quotes/anthony_bourdain_552955?src=t_food):

Food is everything we are. It's an extension of nationalist feeling, ethnic feeling, your personal history, your province, your region, your tribe, your grandma. It's inseparable from those from the get-go.

Food, therefore, is a-product of both; nature and culture, and remains inextricably linked-to-both. Detaching food from these-factors can only result in the-current-system of overproduction and food-wastage (Hudson & Messa, 2015).

Respect for food should definitely be initiated from the-early-childhood, in-the-families, by providing positive-examples to the-young-children. In-addition, to-positive-examples, without education, there can be *no* awareness of the-*real*-value of food, the-magnitude of food-wastage, the-potential-negative- impacts on Human-health and the-Environment, as-well-as of the-best-practices in-managing these-wastes. The-study recommends support-activities and campaigns that increase consumers' understanding of the-value of food and that give a-comprehensive-understanding of the-issue of food-wastage.

5. Conclusion and Recommendations.

Food plays a-crucial-role in economic, ecological, social, cultural, and political-terms. *Everybody has to eat;* the-obvious should *not* go without saying. Each-one of us is totally-reliant on food, *not* only for our-survival, but also for our health, wellbeing, and prosperity. Food is also a-basic-human-right. Kenya is a-signatory to the-United-Nations Universal-Declaration of Human-Rights. Article 25 includes the "right to a standard of living adequate for the health and well-being of himself and of his family, including *food*, clothing, housing and medical care … ".

However, the-current food-production-system is threatened by continuous-increase in human- population, climate-change and associated-natural-disasters, declining soil-fertility, shortages of natural- resources, and growing-costs of agricultural-inputs, notably fossil-fuel-based-fertilizers. This-study also established that *food-waste*, generated-globally, leaves very-deep-footprint, indeed, as Carbon and water-footprint, and stressing land-use and negatively-affecting biodiversity. Besides-its-footprints, food- wastage has both; a-financial and a-social-cost, *not* to-mention its-contribution to global-hunger.

The-problem of food-waste is very-significant; and moreover, it-is ever-growing, and is made even-more-urgent, due-to the-fact that one in four-people, in-Kenya, is considered food-insecure. At a-local-context, the-study identified high-food-waste-share in the-total-waste, of the-university, and contributing to it, behavioral-disrespectful-practices towards food, demonstrated by many-students, in-the-campus. Besides, the-study also emphasized, that food is simply too-precious and valued to-be-wasted!

To-contribute to the-achievement of SDG-12, as a-second-largest-public-university, MU can become a-part of the-solution and has the-potential to-be a-leader in-the-area of food-recovery. To-reduce food-waste and its-negative-impacts, the-study has made several-recommendations.

Recommendations are:

1) The-government and the-university should support-activities and campaigns that increase consumers' understanding of the-value of food and that give a-comprehensive-understanding of the-issue of food-wastage;
2) Detailed-design, testing, and prototyping of the-proposed/designed-composter, should be conducted;
3) To-produce 'green' fertilizer, and reduce food-waste indiscriminate-disposal at the-dump-site, of the-university, the-university should consider implementation of a-closed-loop campus-wide composting-system, and to-explore the-potential of having composters, placed directly near campus-dining-halls;
4) For the-food-waste to-be-used as-animal feed, it should be: (i) first, sorted-out, of any-physical contamination, and then (ii) thermally-treated, to-avoid serious-food transmitted-diseases;
5) Feasibility-studies is essential, to-further-classify the-type and amount, of food-wastes, at-the-campus;
6) To-identify, which industrial-sector/activity might transform and use such-food-wastes; and
7) Reasons for food-waste, at the-institution, should be investigated, and addressed.

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