Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.8, No.8, 2018

Solid Waste Management at University Campus (Part 6/10): Preliminary Estimation of Combustibility and Energy Potential of the Waste

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Abstract
This is a-sixth-piece in a-series of 10. To-examine waste-combustibility, its Moisture-Content (MC), Ash-Content, and Volatile-matter, were established, in-accordance-with the-UNEP (2015); ASTM D3174-12; and ASTM D1102: 2013 alongside-with **ISO 562: 2010, respectively.** A-Tanner-triangle-concept and its-combustibility-requirements informed the-study, and enable to-visualize the-combustibility potential, graphically. The-study established that, for the-waste, at the-subject-university: (a) MC ranges from 10.76 to 57.66 %, with an-average of 36. 84%.; (b) Ash-content ranges from 14.1 to 42.79%, averaging 23.11%; (c) Volatile-matter ranges from 21.78 to 51.34%, with an-average of 38.03%; (d) From the-graphical- judgment of the-Tanner triangle, it was projected that: (i) 37% by weight, of the-total-waste, is high in-moisture-content (57. 66%), and according to the-Tanner-combustibility-requirements *cannot* be combusted, without auxiliary-fuel (e.g., autothermic-combustion), and hence should-be composted, or vermicomposted, or anaerobically-digested, to-generate biogas, and produce a-stabilized-organic-humus, or Microbial-Fuel-Cells (MFCs) can-be-used for electricity-production; (ii) 41% of the-total-waste is combustible; and (e) 87.8% of the-solid-waste has the-capability of being-converted to heat-energy. Waste-to-Energy (WtE) technologies, alongside with selected-myths, surrounding them, were, hence, reviewed. The-current-study is largely-preliminary, therefore, further-studies, such-as: comprehensive Proximate and Ultimate-Analysis of solid-waste, generated by the-university, is further recommended. In-addition, the-study recommends to-conduct a-feasibility-assessment of WtE-technologies, at the-university, *via* decision-matrix. The-findings of this-research provide a-necessary-baseline-data, for the-four-subsequent-studies, in the-series, and also, hopefully, add to-the-body of knowledge, on the-subject-matter.
Keywords: Tanner triangle; Moisture Content, Ash; Volatile matter, Waste-to-Energy (WtE), Composting, Vermicomposting.

1. Introduction.

1.1. Solid waste generation-trends and practices.

It-is-estimated that global-waste-generation will-double by 2025, to-over 6 million-tons of waste, per-day, and the-rates are *not* expected to-peak by the-end of this-century. By 2100, global-waste-generation may hit 11 million tons, per-day (World-Energy-Council, 2016). Municipal-solid-waste (MSW) management-system aims to-handle health, environment, aesthetic, land-use resources, and economic-concerns, related-to *improper* disposal of waste (Al-Waked *et al.,* 2014; Ouda & Cekirge, 2014; Nemerow, 2009). Population, urbanization-growth, and the-rise of standards of living, have all dramatically-accelerated the-municipal solid-waste (MSW) generation in-developing-countries (Guerrero *et al.,* 2013; Minghau *et al.,* 2009). Developing-countries, however, are *not* able to-cope-with the-MSW-generation-growth, and open-landfills remain the-dominant-method of waste-disposal (Ouda *et al.,* 2013; Ouda, 2013).

In-many-countries, MSW-management has often been-regarded as a-public-service with-low priority: a-nuisance and a-burden (Starovoytova, 2018 a; 2018 b; Mutz *et al.,* 2017). In-this-regard, the-2015 United-Nations Sustainable-Development-Goals (SDGs), as-well-as UN Habitat's New-Urban Agenda (2016), call for improvements in-WM-practices, as a-basic-service, to citizens.

On-the-other-hand, *Energy* is a-critical-issue for Africa, where large-number of people does *not* have access to-reliable-energy (Scarlat *et al.,* 2015). For-example, according-to Kenya: Energy Profile (2012), Kenya currently has a-national-electrification-level below 15%. Kenya's energy-sources consist of *imported* fossil-fuels and renewable-sources, which include biomass, hydro, geothermal, solar, and wind. Total-installed-electricity-capacity (2010) is 1,429 MW (Hydro-electric -- 52.1%; Geothermal -- 13.2%; Conventional-Thermal -- 32.5%; Wind, and Others -- 2.2%) (IRENA, 2010). Only about 5% of the-rural-households have access-to electricity, while biomass, mainly-fire-wood, accounts for 77% of the-total-energy, consumed. In-addition, the-Ministry of Energy, in-Kenya, has identified several-long and short-term challenges, such-as: Inadequate-power-supply-capacity, due-to rise in-demand for electricity, which is growing faster, than the-ability to-install additional-generation-plants; Over-dependence on hydro-power, which exposes the-country to-power-rationing, due-to extreme-weather-conditions, such-as drought; Shortage of transformers and overstressed-distribution-network; Dependence on donor-funding for various-projects; Long-delays in-development of power-infrastructure, because building of power generation, transmission and distribution-network is capital-intensive and takes inordinately-long-time from-conception to-commissioning; Low-investments in power-generation by private-investors; Inadequate-sea-port-facilities for handling imported-coal and natural-gas, which are cheaper primary-energy-resources, than petroleum oil-based-fuels for power-generation; High and ever-rising-international-prices of fossil-fuels; Obsolete oil-refinery-system; Conflict with food-security-issues, when developing the-bio-diesel-industry; and Unrealistic-demands by local-communities where energy-resources, like coal, gas, and oil, are discovered (https://softkenya.com/kenya/challenges-facing-energy-sector-in-kenya/).

1.2. Waste-to-energy (WtE) as a-compromise, between high-energy-demands and the-state of the-environment.

The-compromise, between the-energy and the-environment, is a-recent-controversial-issue. Generally, people assume that energy-generation and environmental-protection-activities contradict each-other. More-clearly, most of the-energy-generation-systems exploit the-natural-resources and are a-hazard to the-environment, in-terms of source-depletion and environmental-contamination. One of the-solutions of this-problem is to-implement synergy, between environmental-protection and energy-generation (Alpaslan *et al.,* 2001). Resource-recovery, from waste, can play a-role, in-minimizing the-impact of MSW on the-environment, with the-additional-benefit of providing a-local-source of energy (Scarlat *et al.,* 2015).

There are four-principal-methods for resource-recovery or disposal of MSW (Themelis *et al.,* 2002): (1) *Recovery of materials:* Recovered (by recycling) paper, plastic, rubber, fiber, metal, and glass, can be re-used to-produce similar-materials; (2) *Recovery of energy:* Recoverable-energy is stored, in-chemical-form, in all-MSW-materials, that contain hydrocarbons; this includes everything, except metals, glasses, and other-inorganic-materials (e.g., ceramics, plaster, etc.). By-combusting such-wastes (*via* Mass Burn WtE plants; Fluidized-Bed WtE Plants; Refuse Derived Fuel (RDF), electricity and steam can-be-generated; (3) *Bioconversion:* The-natural-organic-components of MSW (e.g., food and plant wastes, paper, etc.) can be composted aerobically (i.e., in the-presence of oxygen) to carbon-dioxide, water, and a-compost-product, that can be used as soil-conditioner. On the-other-hand, anaerobic-digestion, or fermentation, produces methane, or alcohol and a-compost-product; this method provides an-alternate route for recovering some of the-chemical-energy, stored in the-hydrocarbon-fraction of MSW; and (4) *Direct disposal methods* should be used for any-fraction of the-MSW that is *not* or *cannot* be subjected to-any of the-above-three-methods, plus any-residuals from-these-processes (e.g., ash from-combustion). The-methods involve sanitary-landfill, lagooning, disposal into-surface-waters, in-deep-wells, or at-sea/ ocean. In-developed-countries, the-use of direct-disposal-methods, at-present, is highly-restricted, to well engineered-sites and selected-categories of *non*-objectionable-wastes. In-contrast, in-most-developing countries indiscriminate-waste-dumping is a-common-practice.

Waste-managers and decision-makers, in-developing and emerging-countries, have-to-respond to-these-challenges, and in-recent-times, waste-to-energy (WtE) has-been increasingly-viewed as-a-solution to-the-problems, derived-from rising-waste-quantities, indiscriminate waste-dumping, in-expanding-cities, as-well-as rapidly-growing-energy-demands. WtE refers to a-family of technologies, which treat waste, to-recover-energy, in the-form of heat, electricity, or alternative-fuels, such-as biogas. The-scope of the-term 'Waste-to-Energy' is very-wide, encompassing a-range of technologies of different-scales and complexity. These can include the-production of cooking-gas, in-household-digesters, from organic-waste; collection of methane-gas, from landfills; thermal-treatment of waste, in-utility-size incineration-plants; co-processing of Refuse-Derived-Fuel (RDF), in-cement-plants, or gasification, among-others (Moya *et al.,* 2017). Waste-to-energy (WtE) technologies are assessed in-this-study.

1.3. Previous-research and purpose of this-study.

Recent-study by Starovoytova & Namango (2018 b) have revealed, that both; students and vendors: (i) have-recognized SWM as a-major-problem, at-the-campus; and (ii) perceived the-campus as-dirty and very-dirty. Another-study by Starovoytova (2018 c) estimates, that the-subject-university-campus generates about 5, 111. 65 tons, of mixed-waste, per-year, on-average. Out of which: (i) Food-waste, which is compostable, accounts to 1,891.31 tons/per year; and (ii) Recyclables, included: paper (mixed & corrugated) - 32% (1,635.73 tons/per year); glass - 13% (664.43 tons/per year); plastic and metals, each - 8% (408.93 tons/per year); and E-waste and other-*non*-combustibles, each - 1% (51.12 tons/per year). Her-study is also revealed, that:" Every-day the-university is literally throwing-away profit, as the-waste is just disposed-off at the-dumpsite, without any-formal waste-reduction, at-source, recycling, or composting". The-same-study also recommended further-studies on Moisture-Content and Energy-Potential of the-waste, at the-campus, as a-next-logical-step.

The-need to-increase the-share of renewable-energy and reduce GHG-emissions, along-with raising-environmental-consciousness, to-protect the-environment from polluting and unsustainable- practices, such-as indiscriminate-waste-dumping, practiced at the-university, will in-turn, call for noble- approaches. According to the-World-Energy-Council (2016), "treating *residual*-waste with various Waste- to-Energy (WtE) technologies is a-viable-option for disposal of solid-waste and energy-generation. Many-factors, however, will influence the-choice of technology, and every-region will have-to properly- assess its-specific-context, to-implement the-most reasonable-solution". In-this-regard, a-study, in-the university-context, is necessary, to-identify the-customized and most-practicable-solutions, to-current wasteful-SWM-practices.

To-examine different-alternatives to current-SWM-practices, at the-university, such-as, (WtE)- technologies, currently available, first, the-assessment of the-waste-combustibility and Energy-potential of the-waste, at subject-university should-be-conducted, which in-turn require examination of selected-waste properties. Chandrappa & Das (2012), specified important-chemical-properties, measured for solid-waste, such-as: (1) moisture (water-content can change chemical and physical-properties); (2) volatile-matter; (3) ash; (4) fixed-carbon; (5) fusing-point of ash; (6) calorific-value; and (7) percent of carbon, hydrogen, oxygen, sulphur, and ash. Besides, the-major physical-characteristics, measured in-waste, are: (1) bulk-density; (2) size-distribution of components; and (3) moisture-content. Other-characteristics, which may-be-used, in-making-decision about SWM, are: (1) color; (2) voids; (3) shape of components; (4) optical-property; (5) magnetic-properties; (6) flammability; (7) electric-properties; and (8) putrescence of solid-waste (Buekens, 2005). This-study will be limited-to such-parameters-as: moisture-content, ash, and volatile-matter.

According to Islam (2016):"… characteristics of the MSW stream, like … moisture-content, are critical-factors to determine energy recovery alternatives". The-next-section elaborates on the-waste moisture-content.

Moisture-content (MC) has a-great-influence on the-heat of combustion, as-well-as in-the biological-processes of organic-matter. MC plays an-important-role in-understanding the-nature of the-waste, as high-MC indicates presence of higher-fraction of organic-materials. MC is a-key-factor that greatly-shapes decisions, involved in-the-conversion of organic-waste into-compost and biogas, making use of solid-waste as a-fuel, and designing landfills or incineration-plants (Eyinda & Aganda, 2013). In-particular, MC is a-dominant-factor in-aerobic-composting (Liang *et al.,* 2003). It provides better degradation of organic-matter, and maintains temperature for longer-time-period. Moisture is important for the-activity of microbes, because it increases the-rate of metabolism. The-activity of microbes is at-minimum, when low-moisture is provided (Tiquia *et al.,* 1996). The-moisture is also inversely proportional to the-temperature and the-microbe-activity (Makan *et al.,* 2012). MC is one of the-critical design and operating-parameters, used in-compost-engineering-systems. As a-result, MC-analysis is one of the-most-commonly performed analytical-methods on solid-waste (Ozcan *et al.,* 2016).

On-the-other-hand, moisture increases the-weight of solid-wastes, and thereby, the-cost of collection and transport. In-addition, moisture-content is a-critical-determinant in the-economic-feasibility of waste-treatment by incineration (Vesilind *et al.,* 2002), because wet-waste consumes more-energy (for evaporation of water and in-raising the-temperature of water-vapor), hence, wastes should be insulated from rainfall or other-extraneous-water. For-example, combustion of solid-waste depends on MC; high-moisture-content results in low-net-energy from the-waste i.e., low-calorific-value (Eyinda & Aganda, 2013).

Many-scholars, all-over the-globe, have conducted analysis of MC, Combustibility, and Energy-potential of waste, such-as: Moya *et al.,* 2017; Mugo *et al.,* 2016; Islam, 2016; Dolgen *et al.,* 2015; Ezeah *et al.,* 2015; Ouda *et al.,* 2015; Omari, 2015; Scarlat *et al.,* 2015; Al-Waked *et al.,* 2014; Omari *et al.,* 2014; Ouda & Cekirge, 2014; Khamala & Alex, 2013; Katiyar *et al.,* 2013; Das & Bhattacharyya, 2013; Medina, *et al.,* 2013; Ellyin, 2012; Amber *et al.,* 2012; Yildiz *et al.,* 2012; Ferreira *et al.,* 2012; Kothari *et al.,* 2010; Ryu, 2010; Tsai & Kuo, 2010; Salomon & Lora, 2009; Chang & Davila, 2008; Cheng *et al.,* 2007; Kathiravale *et al.,* 2004; *et al.,* 2003; Themelis *et al.,* 2002; Mbuligwe, 2002; Kumar, 2000; and Leão & Tan, 1997. Studies, at university-context, however, are deficient. In-the-light of the-above-information, this-study is focused on Combustibility, and Energy-potential of waste, at the-subject-university. Its-findings will hopefully assist in the-decision-making on ISWM-system, to-be developed, for the-campus.

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 a).

2.2. Determination of Combustibility.

The-ability of waste to-sustain a-combustion-process, without supplementary-fuel, depends on a-number of physical- and chemical-parameters, of which the-lower (inferior) calorific-value is the-most-important. Theminimum-required lower-calorific-value, for a-controlled-incineration, also depends on the-furnace design. The-combustibility of MSW is determined by analysis and heating-value of MSW, which is the-ash and water-free calorific-value (H_{awf}) expresses the-lower-calorific-value of the-combustible-fraction (ignition-loss of dry-sample). For direct-incineration and energy-recovery, the-waste calorific-value should-be at least 2000-2500 kcal/kg, and 1500-1600 kcal/kg for the-combustion, without additional-fuel. If the-heating-value is below 1200 kcal/kg, it is understood that the-solid-waste *cannot* be economically burned. The-other-method of combustibility-determination is *via* Tanner-combustion-triangle (Worrel & Vesilind, 2008). In-this-study, the-combustibility was determined graphically *via* Tanner-triangle.

2.3. Determination of Moisture Content (MC).

Currently, many-moisture-meters are available, for the-determination of MC, in the-*field*. This-study, however, used proven, traditional *laboratory* oven-drying testing-method. According-to Komilis *et al.* (2012), oven-drying is always part of the-sample-preparation-protocol for quantitative-analysis. Although time-consuming, this-method is precise, straight-forward, and can-be-used to-analyze many-samples, simultaneously. In the-wet-weight-method of measurement, the-moisture-content (MC), in a-sample, was expressed as-a-percentage, of the-weight, of the-material, when wet, whereas in the-dry-weight-method, it was expressed as-a-percentage of the-weight of the-material, when dry. The-study used the *wet*-weight method in-accordance-with the-UNEP, Mapping Solid Waste – II (2015), with *no* correction done, for cross-contamination of wastes.

Apparatus used for the-determination of MC, are: (i) Weighing-device: a-balance, sensitive to 0.1 % of the-mass of the test-sample, and having a-capacity equal to, or greater than, the wet-mass of the-sample to-be-tested; (ii) Drying-device: an-oven, with thermostatically-controlled heating-chamber, capable of maintaining a-temperature of 85 ± 5°C; (iii) Heat-resistant gloves/mitts, and pot-holders, to-remove-samples, from the-oven; (iv) Aluminum-Foil; (v) Clean-plastic-bags; and (vi) Stickers and marker-pen for labeling the-samples.

Representative-samples were collected-randomly, from the-identified-waste-generators, labeled, put in separate-clean-plastic-bags, and brought to the-testing-laboratory, for-testing, within the-same-day. Certain-amounts of waste, from each-sample, were inspected for signs of cross-contamination-with waste- liquids or rainwater, and then weighed to an-accuracy of *not* less than 0.10 kg, and then laid-down as-a-carpet that is max 3 cm-thick, in an-aluminum-foil; the-weight was recorded as W1. Several-samples were then positioned into preheated-fan-assisted-oven, to-allow the-maximum-air-circulation and exhaust of the-moisture-laden-air, and dried to constant-mass at 85 ± 5°C, for 48hours. Afterwards, the-samples were removed from the-oven, and kept in-desiccators, to-allow to-cool, naturally, for another 48 hours. Then the-samples were re-weighed and recorded, as W2. The-moisture-content (% H_2O) is then calculated as follows:

$$\% H_2O = \frac{(W1 - W2)}{W1} x100$$

2.4. Determination of Volatile Matter.

Volatile-matter of a-municipal-solid-waste is a-vapor, released when the-waste is heated. The applicable standards, such-as, ASTM D1102: 2013 and **ISO 562: 2010,** were followed-in for determination of volatile- matter. The previous-sample, used for moisture-content-determination, was again heated in a-covered crucible, to-avoid contact with air, during de-volatilization. The-covered-crucible was placed-into a-furnace at 950 for 2 hours. Then the-crucible was taken-out, and cooled in-desiccator. The-weight difference, due-to de-volatilization was referred as volatile-matter, calculated by the-formula below:

$$\text{Volatile Matter (\%)} = \frac{(\text{Initial weight} - \text{Final weight}) \times 100}{\text{Initial weight}}$$

2.5. Determination of Ash content.

Ash is the-inorganic solid-residue, left after the-waste is completely-burned. ASTM D3174 - 12 Standard-procedure was used for ash-determination. The-remaining-waste-sample from volatile-matter examination was weighted, and placed into the-muffle-furnace at 750 for 1 hour for combustion, until the-waste is completely-converted-to-ash. When all-carbon was burnt, the-sample was cooled to-room temperature, and re-weighted. Ash-content was calculated as:

Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.8, No.8, 2018

$$\text{Ash Content (\%)} = \frac{\text{Weight of Ash} \times 100}{\text{Initial weight}}$$

2.6. Determination of Energy potential.

The-combustion of waste liberates energy in the-form of heat. A-proportion of this-energy is used to-dry the-waste first (as the-moisture-content has to-be-eliminated). The-remaining-energy can then be-used to-generate power and some-useful-work. This therefore illustrates that the-higher the-moisture-content, the-smaller the-energy, available for doing-meaningful-work. This-available-energy can-be-computed as-follows (Eyinda & Aganda, 2013):

The-NET-energy, that can-be-extracted, from-waste is given by: $Enet = Egross - Edry$

Where: *Enet* = Net energy; *Egross* = gross energy; and *Edry* = Energy used to-dry the-waste.

From the-equation above, $Edry = Hs + Hfg$ (Eyinda & Aganda, 2013).

Where: *Edry* = the-energy, required to-dry the-solid waste, *Hfg* = the-heat of vaporization; and *Hs* = the-energy, used to-raise the-temperature of the-waste-water, from the-initial-temperature to vaporization-temperature.

To-find HS; the-following-equation is given: $HS = Mw \times Cp \times (Ts - Ti)$ (Eyinda & Aganda, 2013)

Where: *Mw* = mass of moisture in-solid-waste; *Cp* = Heat-Capacity of water; *Ts* = Vaporization Temperature; and *Ti* = Initial-Temperature.

Finding latent-heat of vaporization, is done by $Hfg = Mw \times Hfg$ (Eyinda & Aganda, 2013).

To-determine the Net-Energy, the-following-formula was derived: $Enet = (M - Mw) \times Cv$ (Eyinda & Aganda, 2013).

Where: *Cv = Calorific value of dry waste;*

Therefore: $Enet = (M - Mw) - [(MwCp\,(Ts - Ti)) + MwHfg]$ (Eyinda & Aganda, 2013).

2.7. Data Analysis.

Microsoft-Excel, for Windows XP-Professional 10; and GraphPadPrism 6.00 for Windows, were used for data-analysis. Descriptive-statistics were also-used to-highlight patterns and general-trends, in the-data-sets.

3. Results and Analysis.

3.1. Moisture Content (MC).

Figure 1 shows waste-samples arrangement, in the-oven, during MC-determination, while **Table 1** shows the-results for MC, for 5 waste-generators, at MU, and **Figure 2** shows comparative graph of MC.

Figure 1: Arrangement of samples in the-oven.

Table 1: Moisture Content for 5 waste generators.

	Stage Market	Laboratories	Administrative Offices	Eateries	Hostels
Wet weight (Ww), kg	1.035	0.790	1.310	0.685	1.360
Dry weight (Wd), kg	0.600	0.705	0.830	0.290	0.855
Weight difference (Ww-Wd), kg	0.435	0.085	0.480	0.395	0.505
Moisture Content, %	**42.03**	**10.76**	**36.64**	**57.66**	**37.13**

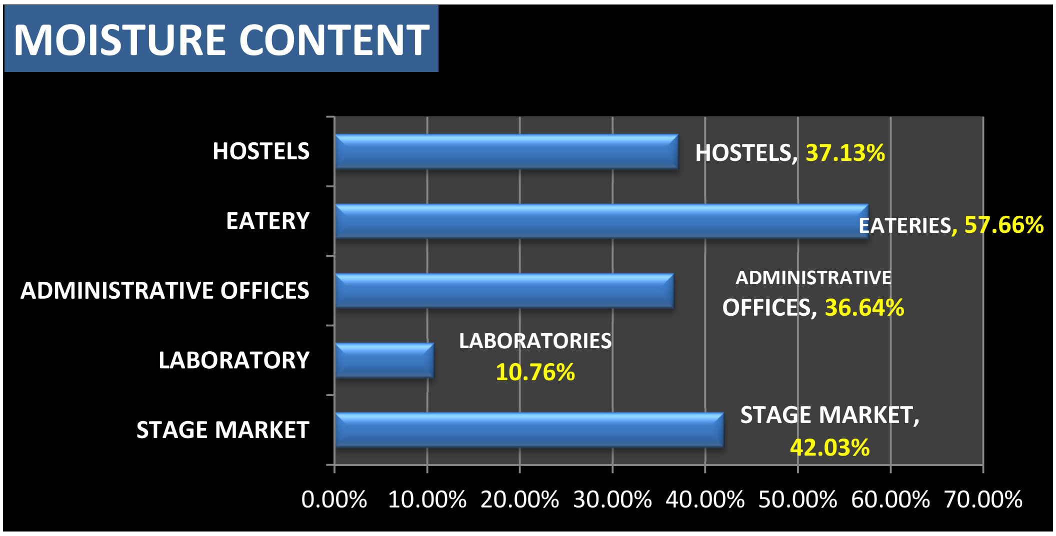

Figure 2: Comparison of MC.

3.2. Summary of results for all-the-parameters.

Table 2 shows the-summary of the-results.

Table 2: Summary of the-results.

Parameter	Units	Range	Mean
Moisture Content (MC)	%	10.76 - 57.66	36.84
Ash Content	%	14.1 – 42.79	23.11
Volatile-matter	%	21.78 – 51.34	38.03

3.3. Energy Potential.

The-annual average-temperature of Eldoret, Uasin-Gishu-County is typically 16.6 ^{0}C (Climatemps, 2017). To-work-out the-net-energy-potential, the-following-values are used: The-Calorific-Value of the-sampled waste was-taken as 12.48 MJ/Kg. This-Calorific-Value was determined, for solid-waste, in-Nairobi, using the-guidelines provided by the-British-Standard, B.S. 1016: Part 5:1967. The-combustion of the-waste is done in an-Oxygen-Charged Bomb-Calorimeter, pressurized at 25 atmospheres (Eyinda & Aganda, 2013); Initial-temperature (Ti) = 16.6^{0}C. From the-thermodynamics of water: Vaporization Temperature (Ts) = 100^{0}C; Heat Capacity of water (Cp) = 4.2 kJ/Kg-K; Latent Heat of Vaporization (Hfg) = 2260kJ/kg; and the-average MC is 36.84%, according to Table 1. The-average mass of moisture (Mw) is therefore 36.84% of 1 kg, which is, Mw= 0.3684kg.

Substituting these values in the Net-Energy Equation:

Enet = (1-0.3684)12480 - [0.3684*4.2(100-16.6)) +0.3684*2260] = 7882.368 - [129.043152+832.584]

Enet = 6920.7408 kJ/kg.

To-determine the *Egross*: $\boldsymbol{Enet = Egross - Edry}$ (Eyinda & Aganda, 2013).

But $E_{dry} = H_s + H_{fg}$ $E_{dry} = [m_w \ x\ (T_s - T_i) + (m_w \ x\ □_{fg})]$ =0.3684 x 4.2(83.4)+(0.3684 x 2260) =961.6272kJ/Kg E_{gross}=6920.7408+961.6272 =7882.368kJ/Kg

The-efficiency of heat-production is worked out as: $Energy\ Efficiency = Enet/Egross X$ 100 =87.8%

This means that 87.8% of the-solid-waste, at-the-university, has the-capability of being-converted to-heat-energy, through processes such-as: incineration, pyrolysis, and WtE-systems, for generating electricity.

4. Discussion.

4.1. Analysis of Results.

4.1.1. MC.

This-study established, that MC ranges from 10.76 to 57.66 %, with an-average of 36.84%. These-findings are in-accord-with reports of previous-investigations, which have found MC ranging from 17.73% to as-high-as 82% (see Kalanatarifard & Yang, 2012; Thitame *et al.,* 2010; Kumar & Goel, 2009; Igoni *et al.,* 2007; Cheng *et al.,* 2007; Gidarakos *et al.,* 2006; Mbuligwe, 2002; and The-World-Bank, 1999), although values of 40%-60% are typically observed. Likewise, according-to Tchobanoglous *et al*. (1993), the-MC of solid-wastes varies, between 15% and 40%, with an-average of 20%. However, MC may reach up to 60% - 70% from-time-to-time, depending, especially, on solid-waste-composition, climate-conditions, and socio economic-structure of the-particular-region. Mugo *et al.* (2016), also-stated, mixed-waste MC of 34.72%.

The-results differed, to-some-extent, with-the-findings by: (i) Katiyar *et al.* (2013), who noted, that MC of municipal-waste varied from 24.3 to 42.2% in-Bhopal, India; (ii) Yildiz *et al.* (2012), who indicated MC-values ranging from 15 to 40%; (iii) Omari, (2015), who noted that the-MC for Arusha municipal-waste ranges from 55.7 to 64.03%, by weight; (iv) Alhassan & Tanko, (2012), who reported that waste MC, from Nigeria gave 10.25%; (v) Chang *et al.* (2008), who reported that MC for solid-waste, from Taiwan, ranged from 37.6 to 65.9%; (vi) Ezeah *et al.* (2015) reported that MC ranges from 43.89 to 55.11, with an-average of 48.80%; and (vii) Das & Bhattacharyya, (2013), also established that MSW at Kolkata, India in-2010 gave MC of 46%, by weight.

It was also revealed, that 41% of the-total-waste, at the-university, fulfilled the-required-values for waste-incineration, without auxiliary-fuel, which should *not* exceed MC of 50%, as reported by Medina *et al.* (2013).

Burnley (2007) believes that utilizing information, related-to moisture-content enables waste-planners to-determine how feasible integrated-solid-waste-management approaches are likely to-be. Chang & Davila (2008), on the-other-hand pointed-out, that waste-planners need-to-bear in-mind, that the-calorific-value of waste-sample decreases with the-increase in-moisture-content. This-study determined 57.66 % moisture-content in food-waste. This is higher, than the-results of Ezeah *et al.* (2015), obtained from the-*food-waste*-samples indicating an-average moisture-content of 48.80%. According-to Ozcan *et al.* (2016), high-organic-matter-content in solid-waste-composition may be a-significant factor, which increases MC. The-findings are in-accord with previous-studies by Ozcan *et al.* (2016); Yildiz *et al*., (2012); and Hui *et al*., (2006). The-relatively-high MC, of *food-waste-samples* from this-study, might be indicative of waste with lower-calorific-values. The-implication being that bioconversion-technologies, such-as AD, are more-suitable, compared to thermo-chemical-conversion-technologies, such-as combustion or gasification. The-implication of this-result is that with some-balancing, the-food-waste may be amenable to-disposable-options, such-as AD. Besides, according to Tchobanoglous & Kreith (2002), moisture can ruin many-materials, in-a-way, that they are impossible-to-recycle (e.g., if paper and cardboard are lay for long-periods of time, outdoors, and the-materials get wet, and also due-to small-yards, where mixing, and contamination, with other-surrounding-materials can-happen).

The-moisture also adversely-affects the-waste-to-energy conversion-process, as the-process consumes more energy to-evaporate-moisture from SW. Moist-waste, such-as garbage, burns *only* after at-least superficial-evaporation of the-moisture, contained (Buekens, 2005). Therefore, waste-to-energy concept receives less-attention in MSW-treatments, especially in tropical-region, where waste with high-moisture-content has been commonly-reported (Silvennoinen, 2013). However, reduction of moisture of MSW would be-beneficial to-convert-waste into-thermal-energy, effectively and efficiently. Use of solar-energy is a widely-practiced-strategy to-reduce-moisture-content, in-many-materials. For-example, Heshani *et al.* (2017), suggest a-method to-reduce-moisture in-MSW, by utilizing solar-energy, by developing a-model for moisture-reduction, where the-parabolic solar-energy-concentration-method is applied to-convert solar-energy into thermal-energy.

4.1.2. Volatile-matter.

This-study established, that volatile-matter ranges from 21.78 to 51.34%, with an-average of 38.03%. These-findings are comparable with the-results of a-study, carried-out in Kolkata, where volatile-matter of 38.53% was reported. The-results are higher, than the-average volatile-matter of the-three-Indian-cities, with 23.7%; (Shodhganga, 2007). The-finding of an-average volatile-matter is much-lower than the-one, reported by Omari *et al.* (2014) of 78.9%.

4.1.3. The ash content.

This-study determined, that the-waste-ash-content ranges from 14.1 to 42.79%, averaging 23.11%. These findings are comparable with the-average ash-content from the-three-Indian-cities, that was reported to be 27.7% (25.94% in Chandigarh, and 27.51% in Mohali and 29.9% in Panchkula). Similar-findings had also been observed for a study carried out in Delhi wherein ash content of 21.8% was reported from LIG-area (Shodhganga, 2007). The-average-finding is higher, than the one reported by Omari *et al.* (2014) of 10.5%.

These-differences can be due-to different-composition of the-waste, varied weather-conditions, during sample-collection, and the-procedure, followed, in determination of the-parameters, among-other- reasons.

4.2. Assessment of combustibility.

MSW can be-classified into ‘dry’ and ‘wet’ materials, on the-basis of their-moisture-content. From the-perspective of energy-recovery, the ‘dry’ fraction can-be-divided into (Themelis *et al.,* 2002): (i) combustible-materials, such-as paper, plastics, wood, etc.; and (ii) non-combustible or ‘inert’ materials, such-as metal and glass. There are three-options for handling the ‘wet’ fraction: (a) combustion; (b) aerobic, or anaerobic-bioconversion; and (c) land-filling. From Starovoytova (2018c), combustibles, in the-university-waste, constitute-approximately 78% (on subtracting 22% of inert-materials from the-total-waste).

According to the-Tanner-triangle, the-wastes that are theoretically-feasible for combustion, without auxiliary-fuel, should-have-met the-following-limits: Moisture-content <50 %; Ash-content <60%; and Combustible-fraction >25% (BSI, 2011). These-limits inform the-combustible-area, shown in **Figure 3** as grey-shaded-region. The-average-values, for the-moisture-content and ash, presented in-**Table 1**, are plotted in a-Tanner-triangle-diagram, alongside-with approximated-Combustibles of 78% (see **Figure 3** in-red), to-see where it falls within the-grey-shaded-area indicating a-combustible-fraction.

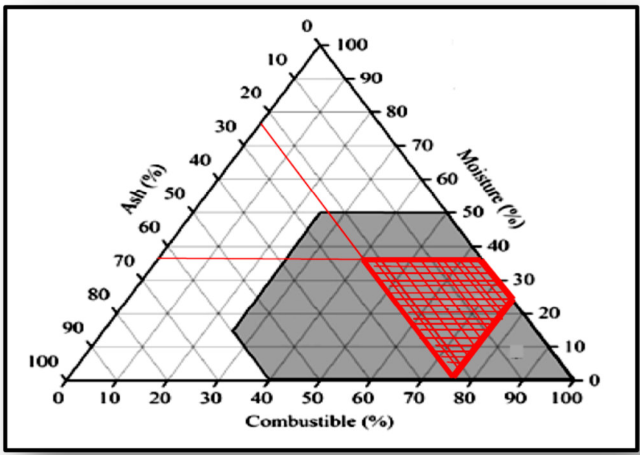

Figure 3: Waste-combustibility-plot.

The-solid-waste, generated in-the-university, however, consists of considerable-moisture (57.66%), and hence, *cannot* be combusted, without auxiliary-fuel, but can be considered for composting. Besides, the-unpleasant-odors and liquids, associated with ‘garbage’ are due-to the-putrescible-organic-components of food and plant-wastes in the-‘wet’ stream. These-materials are less-than 40% of the-total MSW at the-campus; yet they contaminate and complicate the-transport and processing of the-rest of the-MSW. Therefore, it-is generally preferable to-separate the ‘wet’ and ‘dry’ components, at the-source. This is already being done at-some forward-looking-communities in-Canada, Europe, and Australia (Guvenc, 2016).

The-next-section provide some-details on conventional-composting, as-well-as vermicomposting.

4.3. Composting and vermicomposting.

Composting is increasingly-used-method to-treat any-type of organic-waste (REA, 2011; IEA, 2003). For-example, Chandak (2010) described a-successful-community-based-model of composting across several-cities and towns in-Bangladesh. The-project reduced the-land-filling-budget of the-city; Valuable- resource was recovered from organic-waste, in the-form of compost, and the-project also created assured- revenue for 10 years, through sale of compost. 800 jobs were also-created for poor-urban-residents, and 50,000 metric tons of compost is produced every-year, for more-sustainable-farming. The-project avoids greenhouse-gas-emissions in the-amount of 89,000 tons of CO_2-equivalent, per-year. The-project has also-resulted in-behavioral-changes, in-urban-communities, which were-actively-involved in-the-project, as they became convinced-about the-resource-value of waste. The-main-challenges to the-project were the-lack of a-policy-mechanism, to-create-opportunities for developing public-private-partnerships, and absence of the-practice of source-separation of waste, at the-household-level.

In-addition, numerous-studies (see REA, 2011; IEA, 2003) have recommended that composting, or even vermicomposting, can play a-vital-role in organic-waste-management, and in-turn improve agricultural-soil-fertility. According to Starovoytova (2012), the-climate of Kenya is, in some-ways, ideal for aerobic-degradation of wastes. According to Peasey (2000), year-round temperatures, above 20°C, ensure, that the-waste-material will-be-exposed to-conditions, that promote evaporation of moisture, from the-wastes, and conditions, which are favorable, for pathogen-destruction.

The-term *vermicomposting* means the-use of earthworms, for-example, epigeic-compost-worms, such-as *Eisenia foetida*, *Lumbricus rubellus* and *Eudrilus eugeniae,* for composting organic-residues. Earthworms can consume practically-all-kinds of organic-matter and they can-eat their-own-body-weight, per-day, e.g., 1 kg of worms can-consume 1 kg of residues, every-day (Aalok *et al.,* 2008). The-excreta (castings) of the-worms are rich in-nitrate. Vermicomposting, can be further-enhanced with cow-urine; undiluted-urine can-be-used for moistening organic-wastes, during the-preliminary-composting-period (before the-addition of worms.). After the-initiation of worm-activity, urine can-be-diluted-with an-equal-quantity of water, yielding vermicompost with a-higher N-content, in much-shorted-period, in-comparison-with traditional-composting (Munroe, 2004).

On-the-other-hand, traditional-thermophilic-composting characterized by long-duration of the-process, frequent-turning of the-material, loss of nutrients, during the-prolonged-process, and the-heterogeneous resultant-product. However, the-main-advantage of traditional-composting is that the-temperatures, reached during the-process, are-high-enough (over 70 °C), for an-adequate-pathogen-kill.

In-vermicomposting, the-earthworms take over the-roles of turning and maintaining the-material in an-aerobic-condition, thereby reducing the-need for mechanical-operations. In-addition, the-product (vermicompost) is homogenous. However, the-major-drawback of the-vermicomposting-process is that the-temperature (less than 35 °C) is *not* high-enough, for an-acceptable-pathogen-kill. A-study by Ndegwa & Thompson (2001), has examined the-possibility of integrating traditional-thermophilic-composting and vermicomposting, with promising-results.

This-study also revealed, that 41% of the-total-waste is combustible; and 87.8% of the-solid-waste has the-capability of being-converted to heat-energy. The-(WtE)-technologies for such-waste are elaborated on in the-next-section.

4.4. WtE- technologies.

4.4.1. Classification.

Energy-conversion from-waste (waste-to-energy (WtE)) can be-obtained by utilizing different-technologies. Each-one of these WtE-solutions has specific-characteristics, and can-be more or less feasible, depending on many-parameters, including: the-type and composition of waste, its-energy-content, the-desired final-energy form, the-thermodynamic and chemical-conditions, in-which a-WtE-plant can operate, and the-overall energy-efficiency. **Figure 4** shows the-operational-principle and output(s) of the-three-main WtE technologies (thermo-chemical, bio-chemical, and chemical) with their-sub-technologies, and it gives an-overall-picture of the-available-options on the-market. There are also new-developments and research projects, aimed at promoting *alternatives* to-the-most-mature and established-technologies.

The-following-sections provide more-information on the-three-main WtE-technologies.

4.4.2. Thermo-chemical-Conversion.

Thermo-chemical-conversion-technologies are used to-recover-energy, from MSW, by-using, or involving, high-temperatures. The-dry-matter, from MSW, is most-suitable-feedstock for thermo-chemical-conversion technologies.

According-to Ellyin (2012), there are three-*principal*-ways to-recover the-energy-content of MSW, by treating it thermally; *via* pyrolysis, gasification, and combustion/incineration. These-processes are differentiated by the-ratio of oxygen, supplied to the-thermal-process, divided by oxygen, required for complete-combustion. This-ratio is defined as the ‘lambda’ ratio (**λ**), and in-the-case of pyrolysis, it-is equal to zero. Gasification is conducted at sub-stoichiometric-conditions and full-combustion is carried-out, using a-lambda greater than one. Simply put: Pyrolysis $\lambda = 0$, *no* air, all-external-heat; Gasification $\lambda = 0.5$, partial-use of external-heat; and Combustion $\lambda = 1.5$ +, *no* external-heat. Where λ represents: oxygen input/ oxygen, required stoichio-metrically, for complete-oxidation, of all-organic-compounds in-MSW.

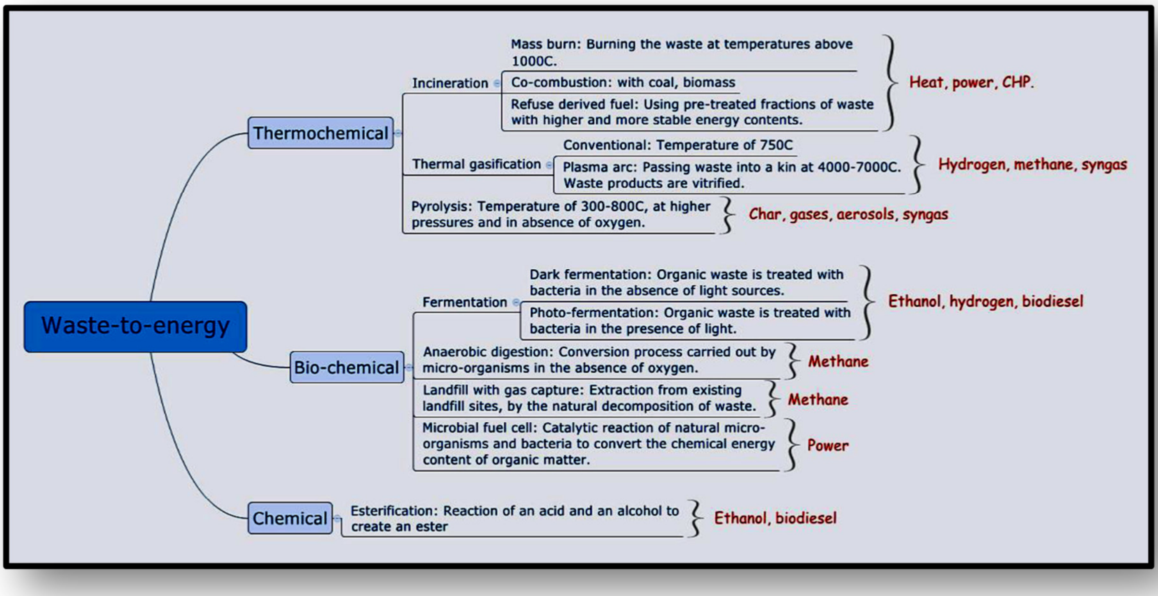

Figure 4: WtE technologies (World-Energy-Council, 2016).

4.4.2.1. Incineration.

Combustion/incineration of MSW is the-complete-oxidation of the-combustible-materials, contained in the-solid-waste-fuel; the-process is highly-exothermic (Consonni & Viganò, 2012). MSW-incineration is the-burning of waste, in a-controlled-process, within a-specific-facility, that has-been-built for this-purpose. The-primary-goal of waste-incineration is to-reduce MSW-volume and mass, and also make it chemically- inert, in a-combustion-process, without the-need of additional-fuel (autothermic-combustion). It also enables recovery of energy, minerals, and metals, from the-waste-stream (EU, 2006). Untreated-MSW is simply incinerated in mass-burn-systems. The-heat, given-off, is converted-into-steam, which can then be passed through a-turbine, to-generate-electricity (co-generation, or combined-heat, and power-plants), or to-produce both; electricity and low-temperature-heat, suitable for space-heating (Kumar, 2000).

The combustible-materials, in-waste burn, when they reach the-necessary ignition-temperature and come into-contact-with oxygen, undergoing an-oxidation-reaction. The-reaction-temperature is between 850 and 1450ºC, and the-combustion-process takes-place in the-gas and solid-phase, simultaneously, releasing heat-energy. After the-waste incineration-process, superheated-steam is produced, and then it-is used within a-cogeneration-system, to-produce energy and heat (Tan *et al.,* 2013). The electric-energy is produced by a-turbine, connected-to a-generator, and the-heat, by a-district-heating-system. The highest-environmental impact of MSW incineration is the-production of greenhouse-gas-emissions (GHG-E), causing public-health-concerns (Ashworth *et al.,* 2014). Besides, there are always about 25% residues, from incineration, in the-form of slag (bottom-ash) and fly-ash. Bottom-ash is made-up of fine- particulates, that fall-to the-bottom of the-incinerator, during-combustion, whilst fly-ash refers to fine- particulates, in-exhaust-gases, which must-be-removed, in flue-gas-treatment. These-residues need further- attention and, in the-case of the-hazardous-fly-ash, a-secure-place for final-disposal. Depending on the- bottom-ash treatment-options, ferrous and non-ferrous-metals can also be recovered, and the-remaining-ash can be further-enhanced to-be-used for road-construction and buildings (Grosso *et al.,* 2011).

In-order-to-implement incineration-system, the-lower-calorific-value of MSW must be at-least 7 MJ/kg, and must never fall below 6 MJ/kg in any-season, and stable-combustible-waste-supply (i.e., at-least 50,000 metric-tons/year) should-be-maintained (Dolgen *et al.,* 2005). At-the-university context, these mandatory-criteria *cannot* be fulfilled, and hence, the-incineration-plant should *not* be implemented. Moreover, in-addition-to high-capital and opeation-costs, of inceneration-facilities, they do emit hamful-substances to-both; the-environment and human-health, such-as: acidic-gases (hydrochloric-acid (HCl), hydrofluoric-acid (HF), sulphuric-acid (H_2SO_4)); particulates; oxides of nitrogen (NO_x); organic-compounds (dioxins and furans); and carbon-dioxide. Also, the-ash contains toxic-elements such-as: arsenic, cadmium, lead, and mercury, and treating the-ash, for the-pollutants beyond-limit is another-costly- affair (Kuras, 2009). Moreover, technology-wise, critics argue that incinerators destroy valuable-resources and they may also reduce incentives for recycling (Zhang *et al.,* 2012; and Klein, 2002).

4.4.2. 2. Gasification.
Solid-waste-gasification is the-partial-oxidation of waste-fuel, in the-presence of an-oxidant, of lower-amount, than that required for the-stoichio-metric-combustion (Thakare& Nandi, 2016; Eremed *et al.,* 2015; Higman & Burgt, 2011), within high-range of working-temperatures (700-900°C) (Arena & Di Gregorio, 2013). The-gasification process breaks-down the-solid-waste, or any-carbon-based waste- feedstock, into-useful-by-products, that contain a-significant-amount of partially-oxidized-compounds, primarily a-mixture of carbon-monoxide, hydrogen, and carbon-dioxide. Furthermore, the-heat, required for the-gasification-process, is provided either by; partial-combustion, to-gasify the-rest, or heat-energy is provided, by using an-external-heat-supply (Higman & Burgt, 2011). The-produced-gas, which is called *syngas*, can be used for various-applications, after syngas-cleaning- process, which is the-greatest-challenge to-commercialize this-plant in-large-scale (Arena, 2012). Once the-syngas is cleaned, it can be used to-generate high-quality-fuels, chemicals, or synthetic-natural-gas (SNG); it can be used in a-more-efficient gas-turbines and/or internal-combustion-engines, or it can be burned, in a-conventional-burner, which is connected to a-boiler and steam-turbine (Albrecht, 2015). It-is-important to-note, that the-heterogeneous nature of the-solid-waste-fuel, mechanical-treatment, ahead of gasification, sensitivity to feedstock properties, low-heating-value of waste-fuel, costly-flue-gas clean-up-systems, difficulty of syngas clean-up, and poor-performance at small-scale, have been a-great-challenge, during-gasification of MSW (Consonni, & Viganò, 2012; Oliveiraa & Rosa, 2003).
4.4.2. 3. Pyrolysis.
Pyrolysis of solid-waste is defined as a-thermo-chemical-decomposition of waste-fuel at-elevated temperatures, approximately between 300^{o}C and 800^{o}C, in the-absence of air, and it converts MSW into gas (syngas), liquid (tar) and solid-products (char). In-this-technology, waste requires the-mechanical- separation of glass, metals, and other-inert-materials. Syngas, gas produced during-pyrolysis-process, is mainly composed of methane, hydrogen, carbon monoxide, and carbon-dioxide. The net-calorific-value of syngas is normally between 15 and 20 MJ/Nm^3 (Zafar, 2014). In-addition, a-recent-study found that after distillation of liquid-hydrocarbons (from the-pyrolysis of plastic-waste), the-resulting-synthetic-product has the-same-properties as the-petro-diesel-fuel (Agarwal *et al.,* 2013). The-amount of useful-products from pyrolysis-process (CO, H_2, CH_4, and other-hydrocarbons) and their-proportion depend entirely on the-pyrolysis-temperature and the-rate of heating (D'Alessandro *et al.,* 2013; Higman & Burgt, 2011).
4.4.3. Biochemical-Conversion.
Biological-conversion-technologies utilize microbial-processes to-transform-waste, and are restricted to biodegradable-waste, such-as, food and yard-waste. Accordingly, the-wet-matter from the-MSW (the biogenic-fraction) and agricultural-waste are the-most-suitable feed-stocks for biochemical-conversion- technologies.
4.4.3.1. Fermentation.
Fermentation is a-process, by which organic-waste is converted-into an-acid or alcohol (e.g., bio-ethanol, lactic-acid, hydrogen) in the-absence of oxygen, leaving a-nutrient-rich-residue. The by-product of ethanol-fermentation is residual-silage, after distillation, and is usually-used for animal-feeding, with recent-focus on finding-ways to-recover the-energy, contained in-it. Practical bio-ethanol-fermentation-plants are large, and an-optimal-sized-plant produces about 200,000-300,000 tons of ethanol, per-year (Braun *et al.,* 2010). By-using-yeast, the-biomass-fraction of MSW, can be fermented, to-generate ethanol, which can be used to-run internal-combustion-engines (Viitez *et al.,* 2000).
4.4.3.2. Anaerobic Digestion (AD).
AD is *only* suitable for processing organic-matter, i.e. biomass. AD is a-process, by-which organic-material is broken-down, by micro-organisms, in the-absence of oxygen, producing biogas, a-methane-rich-gas used as a-fuel, a-digestate, a-source of nutrients, used as fertilizer, and decontaminated-water (Di Maria *et al.,* 2017). AD utilizes the-biological-processes of many-classes of bacteria, and generally consists of four-steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Xu *et al.,* 2002). For that-purpose a-gas-tight-reactor, a so-called anaerobic-digester, is used, to-provide favorable-conditions for microorganisms, to-turn organic-matter, the-input-feedstock, into-biogas and a- solid-liquid-residue called digestate. Biogas is a-mixture of different-gases, which can-be-converted-into thermal and/or electrical energy. The-flammable-gas methane (CH_4) is the-main-energy-carrier in-biogas, and its-content ranges between 50 – 75%, depending on feedstock and operational-conditions (Wellinger *et al.,* 2013). Due-to its-lower-methane-content, the-heating-value of biogas, is about two-thirds that of natural-gas (5.5 to 7.5 kWh/m^3). Another-option is to-upgrade biogas to bio-methane, with approximately- 98% methane-content, which can be used as a-substitute for natural-gas (Wellinger *et al.,* 2013).

The-time of operation, per-cycle, meaning how-long it takes for the-organic-waste to-be-processed by an-AD-plant, is usually 15 to 30 days (Bayard *et al.,* 2010). The-biogas, naturally-created, in sealed tanks, is utilized, to-generate renewable-energy, in the-form of electricity, or heat, with a-combined- heat, and power-unit (CHP). The-bio-fertilizer is pasteurized, to-make-it pathogen-free, and can-be-applied twice-a-year on-farmland, successfully-replacing the-fertilizers, derived from fossil-fuels. The-technology is widely-used to-treat-wastewater, and can-also-be effectively-employed to-treat organic-wastes, from domestic and commercial-food-waste (http://www.biogas-info.co.uk/about/) .

A-large-number of different anaerobic-digester-designs, does exist-worldwide, with varying-levels of complexity. According to Vögeli *et al.* (2014) and Wellinger *et al.,* (2013), AD can be classified by: (i) *Mode of feeding:* Batch or continuous-feeding; (ii) *Temperature range:* Psychrophilic (< 25°C), mesophilic (35-48°C) and thermophilic (> 50°C) conditions, where only the-latter-two are considered economically- viable. Thermophilic-conditions are recommended, when risk of pathogens is prevalent. Alternatively a- pasteurization at 70°C for 1 hour, or a-thermophilic-composting can-be-used, to-inactivate-pathogens for mesophilic-systems; (iii) *Reactor type:* Continuously-stirred-tank-reactors are common, for liquid feedstock, such-as catering-waste, or wastewater, or industrial-sludge, from food-processing, while plug-flow and batch-digesters, are used for solid-feedstock. Solid-feedstock can-be-dewatered, to-be-used in continuously stirred-tank-reactors; and (iv) *Number of stages:* One to multi-stage-digestion is possible.

Besides, according to Andriamanohiarisoamanana *et al.,* (2010), AD can be *Wet or Dry*: this refers to the-AD-feedstock, but the-difference, between the-two, is *not* significant. Wet-AD is 5-15% dry-matter, and can be pumped and stirred; while dry-AD is over 15% dry-matter and can-be-stacked. Dry-AD tends to be-cheaper, to-operate, as there-is less-water, to-heat, and there is more-gas-production, per-unit of feedstock. In-contrast, wet-systems require lower-capital-costs, for installation, but dry-systems tend to be favored for MSW-treatment, as 'dry' anaerobic-digestion-technologies operate with higher-solid-content and produce greater-heat. Moreover, there can be Vertical-Tank or Horizontal-Plug-Flow of a-bio-digester: Vertical-tanks take feedstock in a-pipe, on one-side, and digestate overflows, through a-pipe on the-other. Horizontal-plug-flow is chosen, when there is more-solid-feedstock. The-former is cheaper and simple to- operate, but presents the-risk of having the-feedstock, for inappropriate-periods of time, resulting in- possible-economic-losses. The-latter is expensive, to-build and operate, but the-rate of feedstock-flow in the-digester can be highly-controlled (http://www.biogas-info.co.uk/about/ad/).

The-choice of AD-technology will-depend on many-factors, such-as: type of feedstock, co/single digestion, space (e.g., plants will have to-have a-small-footprint in-urban-areas), desired-output (e.g., more- biogas for energy-production, waste-mitigation, bedding, digestate), infrastructure, and available- grants/financing. It-is very-flexible, as it can be designed, in-multiple-ways, according to the-context in which is intended to-operate.

The-feedstock usually requires pre-treatment, depending on the-kind available. For-instance, waste- food, from supermarket will-require removal of all-packaging, and screening for contaminants, such-as plastics and grit; while others, such-as manure or waste-crops, will need to-be-homogenized, to reach the-consistency, desired for optimum-fuel-output (Wilson *et al.,* 2013).

AD is a-promising-technology, with multiple-benefits, for a-wide-range of stakeholders, ranging from the-local-community, farmers, to government. It-is considered to-be the-optimum-method for handling-food-waste, in an-environmentally-safe-way. While it-is *not* a-new-technology, since it dates from as-back-as 1800s, and experienced continuous-growth, and technical-development, throughout the-recent- years, the-market is rather-small, with huge-room for expansion. The-organic-waste-fraction of MSW in developing-countries is usually-much-higher than in industrialized-countries, and agricultural-waste is also often-available for use as a-co-substrate. Furthermore, many-developing-countries are located in-warm- climates. These conditions make AD particularly-interesting, in our-case.

4.4.3.3. Landfill gas utilization.

Gas-emissions, from landfills and waste-dumpsites, around the-world, are causing global-environmental impacts. Methane, one of the-gasses, emitted, is a-potent-greenhouse-gas, with a-global-warming potential that is 25 times greater-than CO_2. A-study by Themelis & Ulloa (2007) showed, that worldwide, landfills produce about 75 billion Nm^3 of landfill-gasses, and less than 3% of this-potential is used, to-produce energy or heat. Capturing methane-emissions from landfills is *not* only beneficial, for the- environment, as it helps mitigate climate-change, but also for the-energy-sector and the-community.

The-process, of capturing the-gasses, involves partially-covering the-landfill and inserting collection-systems, with either vertical or horizontal-trenches. As-gas-travels, through the-collection-system, the-condensate (water) formed, needs-to-be-accumulated and treated. The-gas will be-pulled from the-collection-wells into the-collection-header, and sent to-downstream-treatment, with the-aid of a-blower. The-excess-gas will be-flared in-open, or enclosed-conditions, to-control emissions, during start-up, or downtime, of the-energy-recovery-system, or to-control the-excess-gas, when the-capacity for energy- conversion is surpassed. Applications for LFG include direct use in boilers, thermal uses in kilns (cement, pottery, bricks), sludge-dryers, infrared-heaters, blacksmithing-forges, leachate-evaporation, and electricity- generation, to-name a-few. LFG is increasingly-being-used for heating of processes, that create fuels, such- as biodiesel or ethanol, or directly-applied, as feedstock for alternative-fuels, such-as compressed-natural- gas, liquefied-natural-gas, or methanol. The-projects, that use cogeneration (CHP), to-generate electricity and capture the-thermal-energy are more-efficient and more-attractive in this-sense (Mostbauer *et al.,* 2014).

4.4.3.4. Microbial Fuel Cells (MFCs).
MFCs are biochemical-catalyzed-systems, in which electricity is produced, by oxidizing biodegradable organic-matters, in the-presence of either; bacteria or enzyme (Rahimnejad *et al.,* 2015). Bacteria are more-likely to-be-used in-MFCs, for electricity-production, which also-accomplish the-biodegradation of organic-matters and wastes. Good-sources of microorganisms include: marine-sediment, soil, wastewater, fresh-water-sediment and activated-sludge. MFCs consist of anodic and cathode-chambers, separated-by a-proton-exchange-membrane. The-anodic-part is usually maintained, in the-absence of oxygen, while the-cathodic can-be-exposed to-air, or submerged in aerobic-solutions. Electrons-flow, from the-anode to-the cathode, through an-external-circuit, that usually contains a-resistor, a-battery, to-be-charged, or some-other-electrical-device. More-information on practical-use of MFCs can be-obtained *via* Starovoytova *et al.* (2014). MFCs are affordable and usually-used in-small and medium-size-facilities, and hence, the- technology is potentially-appropriate in the-university, subject to further-independent-assessment.

4.5. Chemical Conversion.
Under Chemical-Conversion, the-esterification-process involves the-reaction of a-triglyceride (fat/oil) with alcohol, in-the-presence of an-alkaline-catalyst, such-as sodium-hydroxide. A-triglyceride has a-glycerine-molecule, as its-base, with three-long-fatty-acids, attached. The-alcohol reacts with the-fatty-acids, to-form a-mono-alkyl-ester, or biodiesel, and crude-glycerol, used in-the-cosmetic, pharmaceutical, food, and painting-industries. The-alcohol used is usually either; methanol, which produces methyl-esters, or ethanol, with ethyl-esters. The-base, applied for methyl-ester, is potassium or sodium-hydroxide, but for ethyl-ester the-former-base is more-suitable. The-esterification-reaction is affected by the-chemical-structure of the-alcohol, the-acid, and the-acid-catalyst. Biodiesel is used in the-transportation-sector, and can be produced from oils and fats, through three-methods: (i) base-catalyzed trans-esterification of oil; (ii) direct acid catalyzed trans-esterification of oil; and (iii) conversion of the-oil to its-fatty acids, and then to biodiesel. Base-catalyzed trans-esterification is the-most-economical-process http://www.see.murdoch.edu.au/info).

Moreover, so-called *Emerging-technologies,* include: Hydrothermal-Carbonization (HTC); Palletization; Wet-oxidation; freezing (of sludge) (Buekens, 2005); and Dendro-Liquid-Energy (DLE).

From the-above-information, and considering relatively-small-waste-generation-rates, and limited-finances, available, at the-university, a combination of composting, vermin-composting, and bio-methanation plant, incorporating Microbial-Fuel-Cells (MFCs), would help in achieving a better SWM-system. These-technologies were-chosen, for further-examination, on the-basis of lower-capital-cost (ton/year), net-operational-cost, per-ton, complexity of technology, and higher-efficiency, as-compared to-plasma-arc gasification and pyrolysis (Ouda *et al.,* 2015; Sorenson, 2010; Clark & Rogoff*,* 2010; Greater London Authority, 2008).

More-details, for each of the-listed-technologies, including: Diagram, suitable-waste, operational, legal, economic, and environmental-aspects, can be accessed *via* Mutz *et al.,* (2017); and World-Energy- Council (2016). In-addition, any-WtE-project is a-complex-undertaking and should-be-accompanied by a-professional and thorough feasibility-assessment. The-decision-matrix (with 12 parameters) presented in Mutz *et al.* (2017), can assist in-the-examination, of the-suitability of potential-technologies, for specific- contexts. The-study, hence, recommends to-conduct a-feasibility-assessment of WtE-technologies, at the-university, *via* the-decision-matrix.

4.6. Concluding remarks on WtE.
Waste-to-energy technologies (WtE) are promising technologies, especially for developing-countries, to- turn waste into a-useable-form of energy (El-Fadel *et al.,* 2002). Harnessing-energy, from waste, has many-benefits, such-as (Kothari *et al.,* 2010; Greenwood, 2009; Wang, 2009; Kathiravale, 2003; and Voelker, 1997): (i) It helps to-reduce dependency on-energy-imports; (ii) It contributes towards reducing carbon-emissions and meeting-renewable-energy-targets. In-fact, by the-world economic-forum report "Green Investing: Towards a Clean Energy Infrastructure" published in-2009, WtE is identified as one of the-eight-technologies, having significant-potential to-contribute to-future low-carbon-energy- system; (iii) When used for electricity-generation, these-technologies have a-steady and controllable-output, sometimes referred-to-as providing 'base-load' power; (iv) It has very-good-sustainability and greenhouse-gas saving-characteristics, as it makes further use of materials, that have-already-been-discarded; (v) reduces the-land-pressure-problem; (vi) create green-jobs; (vii) reduces the-cost of waste-transportation; and (ix) reduces use of precarious-energy-resources by the- society.

On-the-other-hand, it-is paramount, that recyclable-material is removed first, and that energy is recovered *only* from what remains, i.e. from the-residual-waste. In-addition, WtE can never solve the- problem alone, but rather needs-to-be-embedded in an-integrated SWM-system, that is tailored to the specific-local-conditions, with regards-to waste-composition, collection and recycling, informal-sector participation, environmental-challenges, financing, resource-prices, and other-aspects.

It-is-also-important to-be-aware of several-common-myths, which persist around WtE, such-as:

Myth 1: "WtE is an easy going solution to get rid of all the waste problems in a city"

The-situation is much-more-complex, and WtE needs professional-planning, construction, and operation. Unfortunately, there are several-companies, on the-market, which are inexperienced with the-conditions in-developing and emerging-countries. Decision-makers need-to-be-aware that their-objective is first and foremost to 'sell' their-product, and *not* to-solve the-local-problem of SWM.

Myth 2: "A WtE plant can finance its costs exclusively through the sale of recovered energy"

In-Europe, where calorific-values of waste, and energy-prices, are higher, the-revenue, from non-subsidized sale of energy (in-form of heat and power) might cover operating-costs, but never the-entire-investment and capital-costs.

Myth 3: "With a WtE plant in operation, a big fraction of the energy demand of a city can be covered"

In-reality, energy from household-waste will *only* be able to-contribute a-small-fraction, to-the-overall electricity-demand of a city (~ 5%). Utilization of heat is the-most-efficient-application in-Europe, but hardly-used in-developing-countries.

Myth 4: "You can make gold from garbage; even unsorted waste can be sold with profit to be used for further energy and material recovery"

In-reality, WtE is *not* a-business-model, which generates cost-covering-incomes. Revenues, from energy-sales help-to-cover part of the-overall-costs, of thermal-treatment, *but* additional-gate-fees, or other forms of revenues, are required, to-cover full-costs. In all-countries, waste-management as a-whole, has costs and *cannot* be considered, as a-profitable-business that could depend, exclusively, on the-sale of energy, Refuse Derived Fuel (RDF), and recycling-materials, at current-prices, for these-products.

Myth 5: "Qualified and experienced international companies are queuing up to invest and operate large WtE plants in developing and emerging countries at their own risk"

This is only partly-correct, as experienced-international-companies are presently-reluctant to-invest in-WtE, in developing and emerging-countries. The-legal, financial, and reputational-risks, are high, and any-project of the-private-sector has to-be-bankable.

These-myths are often-kept-alive, and can-obstruct informed-discussions. Besides, WtE-projects are expensive, and constitute a-substantial-financial-risk, for the-university. An-independent-assessment of costs and a-profound-understanding on financial-implications are, therefore, crucial for informed-decision making.

Future-oriented WM-concepts should fulfill economic and ecological-needs. Within this-context, pyrolysis or gasification of high-calorific-waste-fractions (sometimes referred-to-as ATTs (Advanced Thermal Treatments), can offer, in-combination-with power-plants and industrial-furnaces, an-alternative technical-solution, provided that it-is mainly used for selected-high-calorific waste. The-technical-approach represents a-possible-choice, within an-already fully-organized WM-system. However, according-to the-United-Nation Framework-Convention on Climate-Change (UNFCCC): "… in most if not all developing countries the conditions do not exist in a municipal set-up which justifies the application of pyrolysis or gasification. In addition the relatively high operation and investment costs do not justify experimenting with a niche technology for very selective fractions which are seldom found in municipal waste". For-example, on-average, the-capital-investment of WtE plants is approximately three times higher than the present coal-fired power plants (Themelis & Reshadi, 2009). In-this-regard, reduction of waste; separation of waste, at the-source; recovery of materials; recovery of energy; and bioconversion, should be-considered, at the-university, first.

5. Conclusion and Recommendations.

The-study established that, for the-subject-waste: (a) MC ranges from 10.76 to 57.66 %, with an-average of 36.84%.; (b) Ash-content ranges from 14.1 to 42.79%, averaging 23.11%; (c) Volatile-matter ranges from 21.78 to 51.34%, with an-average of 38.03%; (d) From the-graphical-assessment of the-Tanner triangle, it was projected that: (i) 37% by weight, of the-total-waste, is high in-moisture-content (57. 66%), and according to the-Tanner-combustibility-requirements *cannot* be combusted, without auxiliary- fuel (e.g., autothermic-combustion); and (ii) 41% of the-total-waste is combustible; and (e) 87.8% of the-solid-waste has the-capability of being-converted to heat-energy.

Potential of WtE-technologies, for the-campus-waste, were also-examined; it-is-important to-emphasize, however, that WtE-projects should *not* compete with waste-reduction and cost-efficient-reuse and material-recycling-measures. WtE is largely a-complementary-technology, for the-treatment of remaining/residual non-recyclable MSW-fractions.

Recommendations:

(a) Food-waste should-be-composted, or vermicomposted, or anaerobically-digested, to-generate biogas, and produce a-stabilized-organic-humus, or Microbial-Fuel-Cells (MFCs) can-be-used for electricity-production.
(b) 'Wet' and 'dry' waste-fractions should be separated, at source.

Besides, the-current-study is largely-preliminary, therefore, further-studies, are recommended, such-as:

(i) Proximate and Ultimate-Analysis of solid-waste, generated by the-university.
(ii) A-feasibility-assessment of WtE-technologies, at the-university, *via* decision-matrix. Besides, WtE-projects are expensive and constitute a-substantial-financial-risk for the-university. An-independent-assessment of costs and a-profound-understanding on financial-implications are, therefore, crucial for informed-decision-making.

The-findings of this-research provide a-necessary-baseline-data, for the-four-subsequent-studies, in-the-series, and also, hopefully, add to-the-body of knowledge, on the-subject-matter.

6. Acknowledgment.

The-author wishes to-thank Research-Assistants, MIT, SOE, MU, Oyuga Victor Otieno and Ogelo Jared Ong'idi, for their-help in-sample-collection and testing.

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