SOLID WASTE AS A RENEWABLE FEEDSTOCK: A REVIEW

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ABSTRACT

This paper reviews the effect of waste to energy in terms of environmental, energy production, as a tool for diverting waste from landfill and the suitability of adopting energy from solid waste as a renewable energy based on the environment protection authority's classification of waste into biogenic and non-biogenic elements. Lifecycle assessment (LCA) of various waste management methods in terms of environmental and sustainability influences favors waste to energy as the preferred method of waste management. Analysis shows that for every ton of solid waste converted to energy about 376 grams of emission is fossil related compared to 1,833 grams for conventional fuel, like coal. Although solid waste has a lower calorific value as compared to conventional means of energy generation with about one-third of the value for coal, it can generate 600 kWh, all from renewable components, thereby saving lots of fossil fuel from being burned to generate this energy. A case study of solid waste generated at Universiti Teknologi Malaysia (UTM) is also reported in order to show the true status of solid waste as renewable energy.

Keywords: municipal solid waste (MSW), lifecycle assessment (LCA), waste to energy (WtE), greenhouse emission, renewable feedstock, renewable energy, landfill, energy recovery, biogenic, non-biogenic.

1. INTRODUCTION

1.1. Why renewable energy?

The major challenges of the modern world are energy, water and waste as related to their influence on global environmental degradation. Waste, a by-product of materials used by human beings, is seen to have risen from 0.64 kg of solid waste/person/day ten years ago to 1.2 kg/person/day, with a forecast of the increase in the amount of solid waste to be generated by 2025 being 1.42 kg/capita/day of municipal solid waste (MSW).

The declaration by the United Nations General Assembly of 2012 as a year of sustainable energy was followed by support from the UN Secretary-General Ban Ki-moon with new global initiatives to be accomplished by 2030. This helped with the increase in the global share of renewable energy.

With increased concern for nuclear safety following the tragedy of Fukushima Daiichi nuclear power plant, as a result of the March 2011 Japanese tsunami and earthquake, there was great reorientation in global policies and politics with regard to future energy. Many countries, especially developed nations, are opting for a change in energy mix. Germany has already made a drastic commitment for a rapid turn from the use of nuclear energy in its energy mix come 2022 [1]. They have tagged the program "Energiewende" (Energy Transition) which, among others, shall focus on the utilization of renewable energy sources. With this reorientation, renewable energy is seen to have good penetration in all end-use with 17% of the supply of global final energy consumption in 2011, despite the upturn in global financial stability, as a result of having nearly half of all newly installed electricity projects from renewable sources [1].

Europe is taking the lead with 71% of all newly installed capacities being renewable [1]. Presently, more countries, both developing and developed, are putting in place renewable energy targets, with more than half of the 118 countries being developing countries and 109 others having policies supporting the adoption of electrical power from renewable energy.

The benefit of renewable energy differs for nations, from being a major player in rural electrification in developing nations to creating jobs for developed countries. In recent years, countries with policies in place have seen an influx of job opportunities directly or indirectly linked to renewable energy. The number of jobs globally in the renewable energy sector stands at an estimated 5 million, directly or indirectly [1].

1.2. Global contributions of renewable energy as an energy source

Despite challenges like technology, slow adoption of renewable energy policies and the variability of renewable resources, global reports on renewable energy show the share of renewable energy in electricity generation rising up to 19% of the total global electricity generation. From this, about 16% of global electricity generation is from hydro energy and 3% from other renewable energy sources [1]. This is illustrated in Figure-1 [2].

Renewable energy is an all-encompassing resource which is used in many ways to boost global energy security and the economic standing of many nations. Depending on the technology, a renewable source is used in any of the following ways [3]:

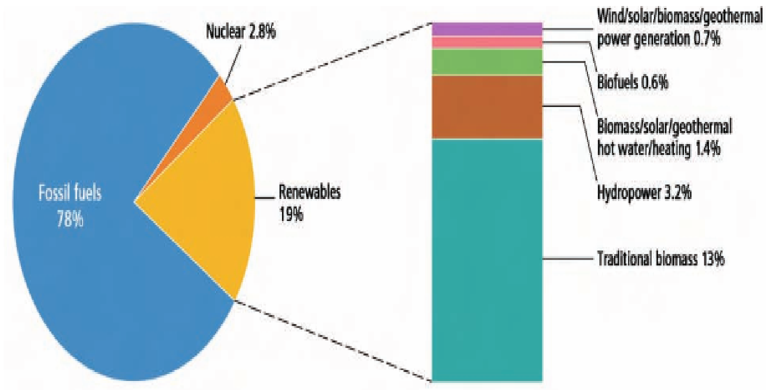

Figure-1. Mean annual growth rate of renewable energy, 2000-2010 [2].

- **Transport fuels:** Bio-fuels, which have an equivalence of 0.73% of gasoline, can be used to offset the amount of gasoline produced globally when harnessed well. For example, a report by Sawin and Martinot [2] shows that, since 2006, there has been a decline in fossil fuel used in the United States. Globally, in 2009, world gasoline production declined by 5% due to an increase in bio-fuel production. The International Energy Agency (IEA) forecasted a boom in bio-fuels. It is expected to supply more than a quarter of world demand for transportation fuels by 2050 [3].
- **Heating:** The IEA report on renewable energy technology 2012 shows that global dependence on renewable energy for heating has grown with over 70 million households using solar power for hot water and biomass for heating [3]. Taking the lead is China with 70% of global energy (180 GWh), comprising an estimated 50-60 million households.
- **Power generation:** Renewable energy in power generation has become indispensable. Most global emissions come from traditional electricity generation from fossil fuels. This has necessitated the aggressive adoption of renewable energy providing 19% of electricity generation worldwide [1]. Examples of countries which have the greatest penetration in renewable energy in electricity generation are, Iceland and Paraguay (100%), Norway (98%), Brazil (86%), Austria (62%), New Zealand (65%), and Sweden (54%), among others [3].

1.3. Types of renewable energy sources

Renewable energy sources may be categorized based on their sources, namely 1) mainstream sources and 2) emerging sources.

1.3.1. Mainstream renewable sources

The mainstream sources are mainly the traditionally researched and developed technologies now put into use globally; these include solar photovoltaic (PV), wind power, hydro power, bio-fuel, biomass, geothermal energy, and so forth. These make up a large proportion of the total amount of energy used globally in the areas of electricity, heating, or transportation [4].

1.3.2. Emerging renewable resources

The new and emerging renewable energy technologies still under development include technologies such as cellulosic, ethanol, enhanced geothermal power, ocean energy, artificial photosynthesis, renewable methanol, and so on [5, 6]. Another resource, often less talked about but nonetheless promising, is solid waste as an alternative energy resource. So many technologies have been developed with much research being conducted to show the viability of solid waste to become a renewable resource. Many researchers classify it as biomass but often differentiate it from biomass due to the difference in composition, moisture content, calorific value, and so forth.

The aim of this paper is to review the contributions of solid waste as a renewable energy resource. Most countries are skeptical of using solid waste because of the perceived environmental effect associated with energy production from solid waste as portrayed by activists campaigning against its adoption as a renewable energy source. This paper will highlight the benefits of using solid waste as a renewable feedstock based on global energy content, waste generation, and environmental effects.

2. SOLID WASTE (GENERATION AND MANAGEMENT)

Waste is any object or material that is unwanted for the purpose it was meant for. Waste, as a by-product of a certain process (industrial waste, used toys, food, and animal remains) that is discarded, can be an input for another process. However, in this article, solid waste is defined as any garbage, refuse or sludge from industrial, commercial, mining, and agricultural operations, or from community activities [7, 8].

2.1. Waste generation

Waste generation is the basis for any activity related to the estimation of environmental impacts of waste disposal or energy recovery. As the global campaign for urbanization continues to manifest, the rate of solid waste generation as a result of the urbanization process is increasing at a faster rate than the urbanization process itself, as evidenced in a study carried out by Hoornweg and Tata [9] that shows an imbalance in solid waste generation increase with urbanization. In ten years, the population of 2.9 billion urban residents generated per capita waste of about 0.64 kg of solid waste/person/day, a sum of about 0.68 billion tonnes per year. However, with an estimated increase in population to about 3 billion residents, the per capita waste became 1.2 kg/person/day, a total to 1.3 billion tonnes of solid waste per year (a 3.4% increase in population to 91.2% of total waste). The report also forecasted an increase in the total number of residents and the amount of solid waste by 2025 to be 4.3 billion urban residents at a per capita waste of 1.42 kg/capita/day of MSW, about 2.2 billion tonnes of solid waste per year [9].

Global expenditure in waste management is also expected to increase with a rise in the amount of waste generated from a value of about $205.4 billion in 2006 to a sum of about $375.5 billion in 2025, estimated from the forecast for the amount of waste generation. The cost increase willl be more in medium- and low-income countries and will increase by more than four to five fold [10]. The implication of this, therefore, is the diversion of funds meant to tackle other services (like health, education or transportation) to waste management because of the high budget associated with waste management. This is more glaring in low-income countries.

2.1.1. Waste generation by region

Examining the distribution of waste generation through different regions, as summarized in Figure-2, Sub-Saharan Africa has an annual contribution to the waste stream of approximately 62 million tonnes per year and is the lowest. This is generally low due to the slow economic and urbanization growth in the region. While the annual waste contribution from East Asia and the Pacific Region is approximately 270 million tonnes and it is increasing rapidly, China accounts for 70% of the regional waste generated. Economic and rapid developments are factors which can be attributed to this huge amount of waste [9]. In East and Central Asia, the annual waste generated is 93 million tonnes. South Asia, on the other hand, generates approximately 70 million tonnes of waste per year. Latin America and the Caribbean generate an annual amount of waste of 160 million tonnes [11]. Most of the waste comes from the Islands. The Middle East and North Africa generate an annual 63 million tonnes of waste. The OECD countries alone generate 572 million tonnes of solid waste annually and that is almost half of the world waste generation [9].

Distribution of waste generation is influenced by economic development, the degree of industrialization, public habits, and local climatic conditions. Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. In conclusion, income level, urbanization and waste generation are highly correlated.

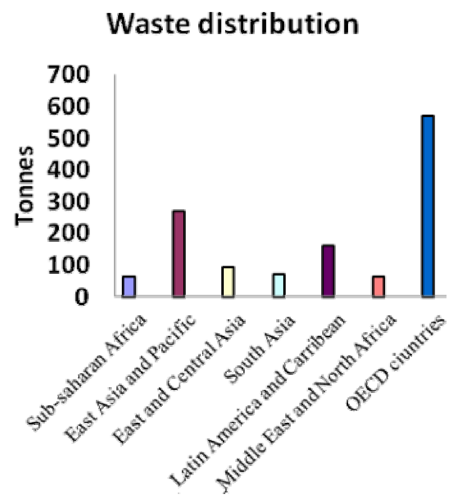

Figure-2. Waste distribution based on region [9].

2.2 Waste management

In most countries, there is a rapid increase in economic activity coupled with population growth making solid waste management a problem, especially in the low- and middle-income economies. This is reported in research by the United Nations Human Settlements Programme (work carried out to prepare UN-Habitat's Third Global Report on Water and Sanitation in the World's Cities) [12]. For an effective study of waste management, Klundert et al. [13] proposed that a study should be based on the concept of technological components, sustainability aspects (social, institutional, political, financial, economic, environmental and technical) and stakeholders (also called actors) presented by the location. This means that implementation of solid waste management is dependent on the region, economy, people, sustainability and technology.

Solid waste management involves several steps that are inter-related [14]: 1) waste definition and generation, this covers the quantity and characteristics; 2) waste handling to include separation and storage; 3) collection, this is the transition stage and a bridge between the first two levels and the final deposit; 4) disposal, the final process in waste management.

2.3. Resource recovery

Solid wastes are not only good for disposal, but their utilization by resource recovery in terms of both material and energy, through a process known as waste to energy (WtE), is important. Although this idea is not new, it has evolved over time from uncontrolled burning by incinerators which are inefficient, uncontrolled, and produce lots of pollution and it has become difficult for this method to be environmental friendly. The present day technology is controlled and efficient energy and material recovery facilities are incorporated with sophisticated air

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pollution controls. With this evolution in technology, WtE is becoming an attractive investment for energy generation and as an alternative to traditional waste management [15]. In addition to reducing environmental pollution concerns, WtE has helped nations in reducing the amount of waste sent for landfill by 90-95% of the total waste generated. The process of modernization has taken over 50 years of research and development in design and technology upgrades, thereby making WtEs viable alternative to landfill and other methods of waste disposal [16]. Apart from extending the life span of landfill and the savings in terms of land requirements for new landfill, energy and jobs are also created through the adoption of WtE. Many major metropolitan areas worldwide have facilities capable of processing 1,000, 2,000 and 3,000 tons of MSW a day with energy production in the form of steam and/or electricity.

Recovery from waste largely depends on certain driving forces from the cities. These forces can be valuable resources, for example in Bamako (Mali) and most African countries where organic waste is used on farms either as decomposed or raw organic waste. In modern cities, like San Francisco, Ithaca, and Adelaide, commitment to zero energy is the driving force and they attain a 55 to 70% rate of recovery from waste in terms of material or energy recovery [17].

3. WtE TECHNOLOGIES

3.1. WtE global perspective

WtE has gained popularity globally, cutting across smaller countries like Bermuda to large countries like China. There has been an average increase of 16 million tonnes of processing since 1995 in 35 countries [18]. Globally about 130 million tonnes of solid waste are combusted every year in over 600 WtE facilities for different purposes, including electricity generation, heating and recovery of materials [18]. Despite the great success in the adoption of the WtE industry, millions of tonnes of MSW still end up in landfill, resulting in a global increase of at least 1.3 tonnes of greenhouse emissions [18].

The adoption of WtE in EU countries can be partly attributed to a directive by the EU Commission to its member countries to reduce the sending of recyclables and combustible materials to landfill [19]. Table-1 gives a summary of WtE capacities in EU countries.

Table-1. Reported WtE capacity in Europe [20].

Country	**Tons/year** (in 1999)	**Kilograms/capita**	**Thermal energy** (gigajoules)	**Electric energy** (gigajoules)
Austria	450,000	56	3,053,000	131,000
Denmark	2,562,000	477	10,543,000	3,472,000
France	10,984,000	180	32,303,000	2,164,000
Germany	12,853,000	157	27,190,000	12,042,000
Hungary	352,000	6	2,000	399,000
Italy	2,169,000	137	3,354,000	2,338,000
Netherlands	4,818,000	482		9,130,000
Norway	220,000	49	1,409,000	27,000
Portugal	322,000	32	1,000	558,000
Spain	1,039,000	26		1,934,000
Sweden	2,005,000	225	22,996,000	4,360,000
Switzerland	1,636,000	164	8,698,000	2,311,000
UK	1,074,000	18	1,000	1,895,000
Total reported	40,484,000	154.5 (average)	109,550,000	40,761,000

Unlike EU countries, Asian countries adopted WtE because of the rising concern for the high rate of waste generation, greenhouse emissions, limitations in terms of land for landfill and the drive to become developed nations. Most of the expansions in WtE facilities are in Asia, with China having the highest number of plants (seven) in operation with an estimated annual capacity of 1.6 million metric tonnes per year [18]. The use of WtE amounts to 314 kg per capita in Japan, 252 kg in Singapore, compared to 105 kg in the US representing about 23% of the global capacity. Table-2 below shows the distribution of WtE facilities in the USA.

Table-2. WtE Facilities in the USA [21].

State	**Number of plants**	**Capacity** (short US tons/day)
Connecticut	10	6,500
New York	6	11,100
New Jersey	5	6,200
Pennsylvania	6	8,400
Virginia	6	8,300

Florida	13	19,300
Total	53	69,600

3.2. Types of WtE technology

WtE technologies are techniques employed to recover energy (electricity and steam), from solid wastes. These can be broadly classified as below [22];

- Thermal processing
- Bio-chemical processing and
- Chemical treatment

3.2.1. Thermal processing

This method employs the use of heat in burning solid waste materials to produce heat, electricity or a number of liquid or gaseous fuels from the waste. These categories can be subdivided into four depending on the type of waste available as the input.

3.2.1.1. Incineration

In waste management, the term “incineration” is understood as the burning of waste with or without the recovery of energy or materials. The heat produced from this process can be used to generate steam to turn a turbine for the purpose of electricity generation or used by boilers in industries or it can even be used for household heating. A study carried out by PREGA [23] estimated that a ton of municipal solid waste (MSW) could generate about 500 kWh of electrical energy through incineration.

Most OECD countries have banned combustion by incineration due to its environmental impacts through the emission of toxics, but the newer technologies generate energy with emissions within targets set by regulators, thereby making them environmentally friendly. An example of the new technology is the fluidized bed incinerator used in China to process about 533,000 tons of garbage to generate 220 million kWh of electrical energy. In Osaka, Japan, an incinerator established in 2002 is in operation with a capacity of 170 tons/day [24]. Another example is that of Brescia Italia, which was established in August 2002; the waste incinerator power plant is able to burn 700,000 tons of refuse and biomass fuel each year. It can generate up to 400 million kilowatt/hours of electrical power and 300 million kilowatt/hours of heat per year, equivalent to an annual saving of 150,000 Teps (Tons of Equivalent Petroleum) [25].

3.2.1.2. Gasification

Gasification is an indirect type of combustion where solid waste is burned with a restricted supply of oxygen. Heat from steam and pressure is used to break the chemical bonds of the waste to form a gas consisting mainly of carbon monoxide, hydrogen and oxygen. These elements are reformed into synthetic gas, which is processed to make a clean, dry fuel gas suitable for use with a variety of internal combustion engines or gas turbines to generate electricity. The gas has a heating value of 10-15% of that of natural gas that can be suitable to burn as fuel or converted to other forms of products, like methanol and synthetic gasoline, that can be used as a substitute for natural gas in gas turbines to generate electricity and heating. This process is a technology proven to be economically and environmentally advantaged [22, 23, 26, 27]. The practical gasification facilities that are in operation include Ze-gen, Shaw Industries, Nexterra, among others [28].

3.2.1.3. Pyrolysis

Unlike gasification, pyrolysis is the chemical decomposition of organic materials by heating, in the absence of oxygen, to produce char, pyrolysis oil and syngas. This technology is at the experimental stage but the pilot projects shows promising high energy efficiencies. Other demonstrated hybrid options are pyrolysis and gasification hybrid systems, and pyrolysis and combustion hybrid systems [22, 23, 28 and 29].

3.2.1.4. Plasma arc gasification

This method uses a high electrical energy form of an electrical arc to create a high temperature (up to 6000^{o}C) region. Due to this high temperature, organic waste materials in the stream are broken down into their elemental gas components (carbon monoxide and hydrogen). The inorganic waste can be put to other uses when extracted, for example in construction. So far, this process is in its early stage and is used only in small capacities ranging from 5-100 tonnes per day. The major disadvantage of this method is that it requires a lot of electricity for the processing of materials, but it is a clean technology with benefits and less or no waste [22, 23, and 29]. The plant located in Utashinai, Japan, has a capacity to produces 7.9 MW of electricity from 300 tons of waste per day [30].

3.3. Energy conversion

To generate electricity from solid waste, the first step is to convert the solid waste into other forms of useful energies, like mechanical or chemical energies. Several options exist for conversion of those resources from their energy status into electricity. This, however, depends on the type of product from the WtE technology, either syngas (which is a function of the level of purity) or heat from combustion.

3.3.1. Internal combustion (IC) engines

These are the most common means of conversion technology. They are robust and stationary, with great similarity to conventional automobile engines. Medium quality gas can be used in electricity generation with a range of 30 kW to hundreds of kilowatts (2000 kW) [28, 29]. Economic and flexibility advantages make the IC engine a suitable choice for small landfills or for small generating capacities because landfill gas can be exhausted with time and the IC engines can be moved to alternative locations easily since they are dynamic and flexible.

Despite their reliability and efficiency as equipment for generating electricity from fuels, including landfill gas, it has had some setbacks: the presence of

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impurities in the gas poses serious problems to the engine that can lead to corrosion. The most common impurities in the gas are a chlorinated hydrocarbon that reacts under the extreme heat and pressure of the IC engine. Another worrisome area is the air/fuel ratio that fluctuates with the gas quality. There is also an environmental concern when using IC in the form of NO_X produced by older designs of IC engines; however, newer designs are equipped with technologies to reduce these NO_X emissions [29].

3.3.2. Gas turbines

This is another turbine that uses quality gas for electricity generation, both on-site and off-site. Gas turbines generally require higher gas flows than IC engines for economic optimization; this makes them more useful in large landfills where there is a high gas flow. They range from 500 kW to 10 MW mostly for landfills of 2 MW to 4 MW according to the US Environmental Protection Agency [29] classification.

The disadvantage of the gas turbine is that additional energy has to be consumed in gas compression before use in the gas turbine. Gas turbines are uneconomic in idle mode because the amount of gas consumed is almost the same as when they are generating power [29].

3.3.3. Fuel cells

This emerging technology has proved to be highly efficient with less environmental effect and is capable of generating 1 to 2 MW. Fuel cells can be used with a variety of waste processes products, like landfill gas or syngas from gasification and pyrolysis. The fuel cell operates based on the basic principle of chemical energy conversion into electrical and heat energy [29].

3.3.4. Steam turbines

This is one of the oldest conversion techniques used in the generation of electricity and heat for district heating. It is mostly associated with incineration/combustion where the heat generated is used to produce steam to turn these turbines. The efficiency of this type of conversion is usually very low; however, using a combined cycle will improve the efficiency [30]. They can be used for large power generation plants of several thousands of kilowatts.

4. SOLID WASTE AS A RENEWABLE ENERGY

The global quest for energies that are mild to the environment and sustainable in nature is on the rise because of the increased environmental effect of greenhouse emissions from landfill and energy-generating plants. On the other hand, the strong wave of urbanization that is on-going is a serious threat to conventional sources of energy, which can become depleted after rigorous usage. Urbanization can also be felt in the high stream of waste that is generated for disposal, resulting in land scarcity.

Most countries have put in place a waste management system that they feel is suitable for the systems they are operating, which include, but are not limited to, landfill, burning to generate energy, non-formal composting, re-use and recycling. Although many nations are employing re-use and recycling efforts to curb the growing waste stream, still the average amount of waste generated per person is on the increase. This growth, coupled with the global shift in electricity generation from conventional fossil fuel to renewable energies, has forced some communities into taking another look at the option of harvesting energy from solid waste through different WtE technologies for the production of clean, renewable, and climate friendly power and providing efficient and safe waste management.

As the global focus on greenhouse gas emissions through energy initiatives/solutions continues to take center stage, then a global perspective on the issue of renewable energy definition and classification needs to be discussed, especially as it affects solid waste as a potential for renewable energy sources and waste management in the future.

4.1. Characteristics of a renewable energy

Several people and different organizations tend to give various definitions of this topic. The Energy Information Agency (EIA) defines renewable energy as "Energy resources that are naturally replenishing but flow-limited". They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include: biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action [31]. According to the EIA, renewable energy should be defined based on its source. From the definition of renewable energy, it can be concluded, therefore, that for any source to be considered as renewable, there are three basic criteria that should be met.

- The resource should be naturally inexhaustible with time. This means that this energy source can be easily replenished in its original from within a time frame.
- There should be flow variation, which is great variability in energy content per period. This gives renewable energy sources unique characteristics.
- Availability.

4.2. Sources of renewable energy

According to various energy sources [4, 31, 32, 33], biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, hydrogen, methanol and tidal energy are examples of renewable energy sources.

4.2.1. Wind

Wind energy is the highest source of energy in the renewable community. In 2009 it experienced an increase of 48% in a period of one year [30] which accounted for the greatest increase in the world's renewables. Produced as a result of climate and geography [33], it is a source that is pollution and radioactive free. Wind energy developed from traditionally being used as water pumps to harnessing electrical energy and is used as a substitute for the conventional fossil fuel system of electricity generation. Offshore wind speeds are usually higher than those on land by almost ~90%, and those on high lands are faster than those of lower locations. This gives offshore resources a higher contribution to global energy. The availability of these wind resources in such a variety of areas gives wind energy a long-term technical potential five times that of current total global energy production, or 40 times current electricity demand, if wind turbines are installed in areas of higher wind speed believed to be a good source of energy [34].

4.2.2. Water

Similar to wind, water is the Earth's natural resource that is in continuous flow. Water has been an energy source from its use in operating mechanical equipment for irrigation to the modern days where flowing water is converted to electricity by the use of modern turbines designed for the purpose. Hydro power is the greatest contributor to the global growth in renewable energy at 16% of the total 19% of the global renewable energy penetration [1].

4.2.3. Biomass

When tapped, the energy stored in plants as a result of photosynthesis is called biomass energy. With good conversion technology, biomass is a good source of heat, electricity and transportation fuels. Biomass is a natural battery for solar energy, when biomass products are burned the stored solar energy used by the plants during the photosynthesis process is released. Biomass is sustainable in nature and, if there is a balance between the usage and the growing of new resources, the battery will last indefinitely [35].

4.2.4. Geothermal energy

Geothermal energy is a form of heat energy extracted from the depths of the Earth. The Earth's heat is made of two parts in a proportion of 1:4. The two heats are: the heat from the original formation of the planet and heat from the radioactive decay of minerals [36]. The heat for geothermal energy comes from the depths of the Earth to the Earth's core, that is, a distance of about 4,000 miles (6,400 km) [36, 37]. A high temperature of about 5,000^{o}C is experienced at the core. This high temperature and pressure create magma that heats up rocks and water on the Earth's crust to a temperature of 371^{o}C [37]. Geothermal energy is an old form of energy used in ancient times; it was used in hot springs for bathing, while in some places in modern times it is used for space heating for electricity generation.

4.2.5. Solar power

Solar power is the most available source of energy being derived from the sun in the form of radiation. Energy harvesting/conversion of solar power depend on photovoltaic and heat engine technologies. Solar power has historical applications that include applications in agriculture (processing and storage of produce), local heating, lighting, and so forth. The modern application of solar power is in electricity generation, space heating and cooling, through modern technologies and architectures. The application of solar energy has a wide application for example day lighting, and solar hot water, solar cooking, and high temperature process heat for industrial purposes, and so on.

4.3. Energy from solid waste

For many years, opposition to the classification of solid waste (MSW) as a renewable energy resource has been global among environmental activists and regulators. This stand can be on two fronts: 1) experiences from the incineration of solid waste largely characterized by high levels of toxic emissions form toxins and furans; 2) perceived competition between recycling and energy recovery; making most nations opt for waste reduction at source rather than reducing waste in terms of recovery as they feel it will directly influence the increase in waste generation which will invariably increase the environmental effect [38].

4.3.1. Energy recovery from solid waste: A tool for waste management

Several studies/lifecycle assessments (LCAs) have been conducted with the aim of ascertaining the effect of energy recovery from solid waste on the environment or to compare the various methods of waste disposal to energy recovery. In a study conducted for Eskisehir in Turkey to determine the best option of waste management to meet the European landfill and packing waste directives for the city, Banar *et al*. [39] developed five scenarios; landfill (92.7%), a 50% separation for recycling, recycling and composting, recycling and incineration (85%), and 100% incineration, respectively. In conclusion, they found that each scenario has a unique effect based on an impact category, with all scenarios with recycling of materials having the least effect on human toxicity; but the best scenario, in terms of global warming potential, is the scenario with the option of recycling materials and incineration for energy recovery.

Another study by Khoo *et al*. [40], using gasification-pyrolysis for waste conversion into energy for Singapore, revealed that energy recovery by the gasification-pyrolysis method is the best in terms of its environmental effect. In comparing the environmental impacts of landfill with composting and recovery from landfill gas in Tehran, Abduli *et al*. [41] showed that the composting and landfill scenario has a higher environmental impact as compared to recovery form landfill gas since it involves energy recovery from landfill gas. Morris [42] made a study and compared the use of MSW, natural gas and coal for electrical power production in terms of climate impact. From the results of the LCA conducted, the author found that natural gas has less influence on emissions than WtE and coal, while WtE is a better option than coal in terms of emissions.

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4.3.2. Solid waste energy recovery: Impacts on the environment

The global importance or benefit of all renewable energy technologies is the reduction of the environmental burden in terms of emissions that comprise toxic gases arising from the production of energy and other energy related activities. Energy recovery from solid waste technologies also, like any other renewable energy technology, is associated with this aim. WtE, apart from its significant waste reduction, also contributes to the reduction of pollutants that cause both local and global environmental effects. In a study conducted to identify the impacts of renewable energy, the IEA [43] discovered that for every ton of MSW there is 1,100 kg of CO_2 emissions per kWh in any conventional conversion system and 1,833 grams of CO_2 is released per kWh of electricity produced in any conventional conversion system. In further analysis it has been shown that in any WtE conversion only 20-40% of the carbon content is from fossil sources, such as plastics, that are considered non-renewable, while the rest comes from biomass, which is considered to be a renewable source. The total CO_2 emissions from the non-renewable elements per kWh are thus 367 grams and this is just about 20% of the total emission per kWh [43]. Figure-3 compares the emissions from solid waste and other non-renewable sources of energy in the production of 1kWh of electricity.

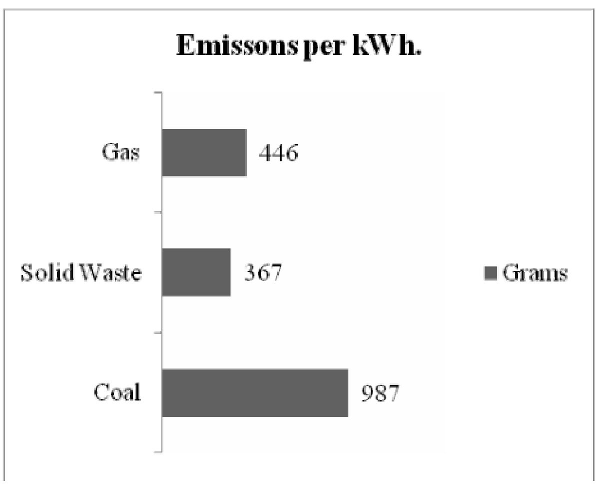

Figure-3. CO_2 emissions from MSW compared with fossil fuel sources [43].

To analyze the emissions from solid waste energy conversion into the environment, illustrations were used as those shown in Figure-4. The total emissions from an average landfill of 1 ton of solid waste will have about 70 kg of methane released, which is equivalent to 1, 610 kg of CO_2 considering methane has a global warming potential 23 times that of CO_2. These methane releases are all avoidable if energy recovery from solid waste is used. Modern landfills are equipped with facilities that can extract about half of the methane and use it for energy production. Generating energy from solid waste has a double benefit: a net reduction of emissions as shown in Figure-4 in terms of avoided emissions from landfill gases and avoided emissions from the generation of energy through conventional methods.

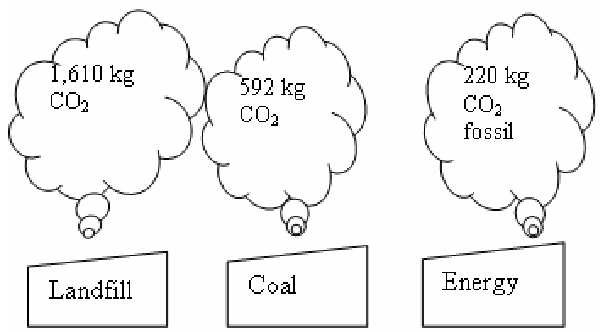

Figure-4. Avoided emissions from energy recovery.

Avoided emission

$$= CO_2E - CO_2L - CO_2C = 220 - 1610 - 592$$
$$= -1982 \text{ kg of } CO$$

where

CO_2E = emission from conversion
CO_2L = emission from energy landfill
CO_2C = emission from coal

Mass burning has become the dominant WtE technology, because it is simple in terms of operation and has a relatively low installation cost. The popularity of mass burning led to the listing of WtE plants in 1980s as major sources of emissions in the USA by Environmental Protection Agency (EPA). However, in 1995 the Maximum Available Technology regulations were produced by EPA in the USA, and the players in the WtE industry spent more than a billion dollars on pollution control to be able to compete with those that release less emissions. With this investment, WtE became a source of 2800 MW with less environmental impact compared to other sources of electrical power [44].

4.3.3. Energy recovery as a tool for landfill waste diversion

Despite reported global reductions in emissions from WtE facilities, critics of energy recovery from solid waste oppose additional facilities for energy conversion attributing it as an enemy to the recycling and re-use options of waste management aiming to reduce waste from the source. Although, even with the best recycling facilities, there is some residual waste taken to landfill, as shown in Figure-5 [38], the remaining waste by analysis is enough for an energy conversion facility to proceed.

America, alone, contributes 20% of global waste (1.81 kg/person/day) [39]. From Figure-5, it can be seen that there has been a significant increase in recycling rates over the decades, with 50% of the total waste going to landfill after the recycling, composting and incineration processes [39]. This means more emissions since, for each ton of

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waste sent to landfill, greenhouse gas emissions in the form of carbon dioxide have also increased by at least 1.3 tonnes, due to the production of methane, which has 23 times the global warming potential of CO_2. Residues of waste in landfill also contaminate adjacent water long periods after closure. But, with the availability of new WtE technologies, only 10% of the waste will go to landfill while cleaner energy and materials can be recovered from the process [45].

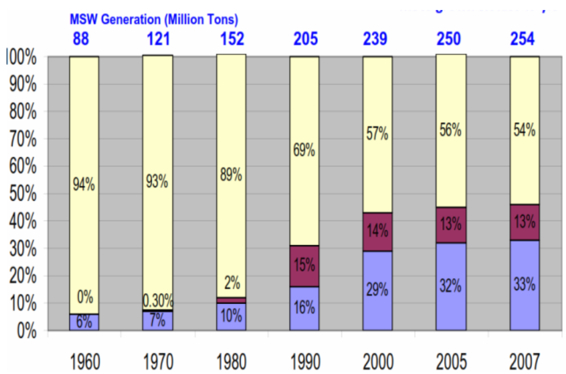

Figure-5. USA waste generation, landfill, recycling and energy recovery [38].

Unlike America, the European Union has consideration for energy recovery from waste producing EU directives (Directives 1999/31, 2004/12 and 2008/98) [46] on the need to reduce the amount of waste going to landfills by 50% by 2030. These make European countries consider available options for reducing the amount of waste generated and taking care of the remaining waste that should be taken to landfill. Many countries formulate laws to guide them towards attainment of these directives. Energy recovery clauses were included in these laws, for example in the UK, the Waste Strategy Review for England 2006, apart from upholding household recycling and composting, also included the need for a clear role for energy from waste as a tool in waste diversion from landfill, but not at the expense of waste reduction or recycling [45]. The EU Renewable Energy Directive of 2001 included in its renewable energy classification energies from the biodegradable components of industrial and municipal waste [45], as seen in Table-3.

Table-3. Reported WtE capacity in Europe [45].

Country	**Recycled/composted and other** (per cent of total)	**Landfill** (per cent of total)	**Incineration** (per cent of total)	**Waste per capita** (kg)
Netherlands	65	3	32	624
Austria	59	31	10	627
Germany	58	20	22	600
Belgium	52	13	35	469
Sweden	41	14	45	464
Denmark	41	5	54	696
Luxembourg	36	23	41	668
Spain	35	59	6	662
Ireland	31	69	0	869
Italy	29	62	9	538
Finland	28	63	9	455
France	28	38	34	567
UK	18	74	8	600
Greece	8	92	0	433
Portugal	3	75	22	43

4.3.4. Energy production from solid waste

The main objective of any chosen waste management method is volume reduction, which indirectly reduces emissions from waste when disposed of. One of the solutions is energy recovery from waste: this method serves the dual function of volume reduction as well as energy recovery.

Solid waste components have different heating values, thus the total energy produced from WtE varies according to the composition of the waste stream [47]. Typically, after recycling, the calorific value of a tonne of

MSW has a heating value of about one-third of that of coal (8-12 MJ/kg for MSW and 25-30 MJ/kg for coal) this can give about 600 kWh of electricity [47]. This is shown in a study conducted by Abdur [48] for the Prospect of Electric Energy from Solid Wastes of Rajshahi City Corporation, a Metropolitan City in Bangladesh, where the calorific values for the waste with high moisture content was found to be 7.94 MJ/kg which can produce an estimated 3.5 MWh/day of electricity for the city. In a similar study for Iluru in India, it was found that, based on laboratory and experimental results, the waste can have up to 1,080 kcal/kg and 1,030 kcal/kg, respectively, which is expected to generate theoretically about 500-600 kWh of electricity [49]. In a study on the feasibility of energy generation from solid waste in Dhaka, Bangladesh, the author, referring to a World Bank/ADB mission, states that the typical solid waste of Bangladesh has a calorific value of 770-1,444 kcal/kg (as received), 1,611-2,389 kcal/kg (air dry) and 1,833-3,444 (oven dry) [23].

4.3.5. Solid waste as a renewable source

Countries in the EU, USA and Australia categorize energy from waste as renewable and non-renewable. In addition, they consider as renewable energy only that from elements considered to be renewable sources, popularly called biogenic elements [43, 50]. The total energy produced from solid waste is the total energy from both elements. The position of solid waste in the renewable energy category, according to EPA's definition, is dependent on the energy recovered from the renewable element of the waste stream [31]. To estimate the amount of energy that will be attributed to renewable energy, EPA characterized the total amount of waste generated (materials available for energy recovery, materials for discard to landfill, recycling, re-use, etc.) based on their type, with their respective energy content as shown in Table-4. The waste is further classified as biogenic and non-biogenic as in Table-5. The amount of waste from the characterization is multiplied by the respective energy content and added based on the elements. The total contribution of renewable elements is the total heat content from the biogenic elements.

Table-4. Typical heat content of materials in municipal solid waste (MSW) [31, 48, 49, 50 and 51].

Materials	Million Btu per ton
Plastics	
▪ Polyethylene terephthalate (PET) ▪ Polyethylene terephthalate (PET)	20.5
▪ High density polyethylene (HDPE)	38.0
▪ Polyvinyl chloride (PVC)	16.5
▪ Low density polyethylene/Linear low density polyethylene (LDPE/LLDPE)	24.1
▪ Polypropylene (PP)	38.0
▪ Polystyrene (PS)	35.6
Other	20.5
Rubber	26.9
Leather	14.4
Textiles	13.8
Wood	10.0
Food	5.2
Yard trimmings	6.0
Newspaper	16.0
Corrugated Cardboard	16.5
Mixed paper	6.5

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Table-5. Type of renewable [31].

Renewable (Biogenic)	**Non- renewable** (Non-biogenic)
Newsprint Paper Containers and packaging Textiles Yard trimmings Food wastes Wood other biogenic Leather	Plastics PET HDPE PVC LDPE/LLDPE PP PS Other plastics Rubber Other non-biogenic

5. CASE STUDY

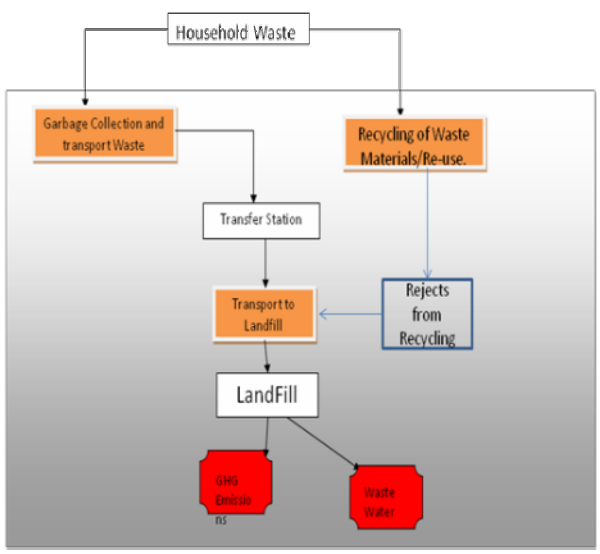
In order to investigate the true status of solid waste as renewable energy, an LCA approach using GaBi[TM] software was conducted on waste generated at Universiti Teknologi Malaysia (UTM) [52]. The waste components and percentages are as shown in Table-6. The percentages used in calculating the total elemental components are given in [53].

Table-6. Waste constituents of UTM.

	Type of waste (Million tonnes/year)						
Year	**Paper**	**Plastics**	**Wood**	**Metal**	**Polyethylene**	**Organic**	**Others**
2009	0.57	0.55	0.81	0.03	0.62	1.09	0.14
2010	0.63	0.60	0.89	0.03	0.68	1.2	0.16
2011	0.65	0.62	0.92	0.03	0.7	1.22	0.16

5.1. Material and method

In order to perform the study, two LCA scenarios were formulated; the recycling/landfill scenario and the WTE/landfill scenario, as shown in Figures 6(a) and 6(b). In the recycling and landfill scenario, it was assumed that all non-biogenic materials and other recyclable and reusable materials were considered to be out of the waste stream because they are taken out, although it was not reasonable to say 100% of these materials were recovered as recyclables; hence, about 50% was considered as been recycled. While in the second case the WtE (energy recovery)/Landfill scenario, all the waste generated was considered for energy recovery since 80% or more of the waste stream may be able to release energy when subjected to certain conditions. The remains from the WtE shall be taken to landfill. The landfill is assumed to last for 100 years and also gasification WtE technology was used as a means of conversion. This method was chosen because of its proven efficiency, and ability to process waste that has considerable moisture content and low heat value, which is a typical characteristic of waste in tropical regions like Malaysia [54, 55, 56]. The functional unit is the total waste accrued from the university in 2011. The aim of the LCA is to show the effect of recycling vis-a-vis energy recovery in terms of emissions and electrical power.



(a)

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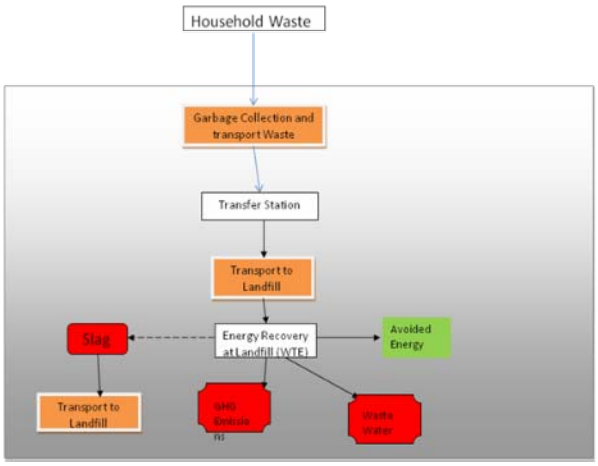


(b)

Figure-6. LCA scenarios in the UTM case study; (a) recycling/landfill scenario, (b) WtE/landfill scenario.

5.2. Results and discussions

Figures 7 and 8 show the results of the LCA simulation, categorized in terms of the amount of emissions associated with all scenarios: 54 kg of carbon dioxide equivalent emissions in the recycling scenario with no energy recovery, while in the WtE scenario, the emissions significantly reduced from 54 kg to -0.98 kg of emissions to fresh water and -0.21 kg of emissions to sea water with an energy recovery of about 12 MW of electricity from the waste.

From the results, it can be seen that there is a significant reduction in emissions with significant amounts of energy recovery. The performed LCA does not include the energy required to manufacture the materials from the cradle.

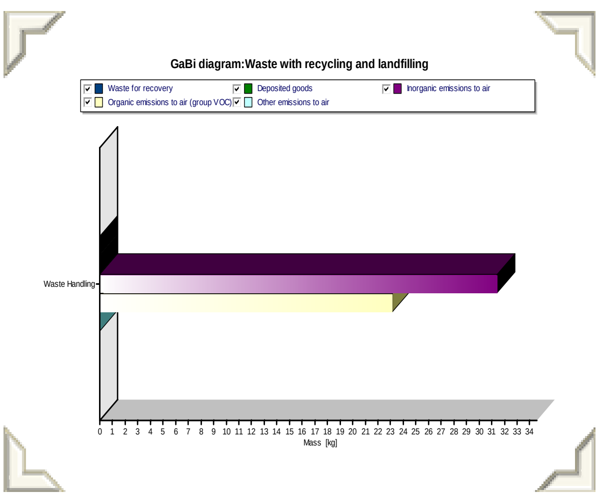
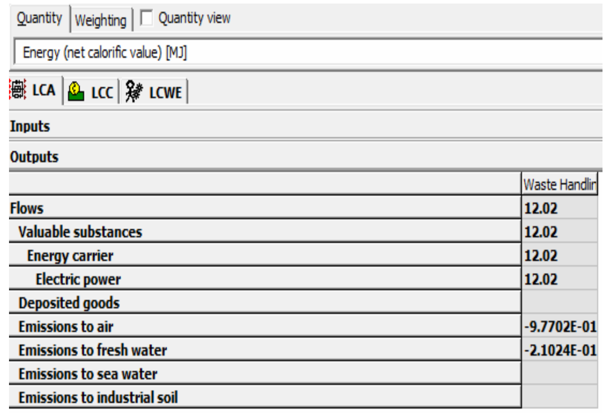


Figure-7. Simulation results for recycling scenario.



	Waste Handlin
Flows	12.02
Valuable substances	12.02
Energy carrier	12.02
Electric power	12.02
Deposited goods	
Emissions to air	-9.7702E-01
Emissions to fresh water	-2.1024E-01
Emissions to sea water	
Emissions to industrial soil	

Figure-8. Simulation results of energy recovery scenario.

6. CONCLUDING REMARKS

Based on LCAs, global indications are that solid waste shows a significant leap based on sustainability indicators. The indicators are in the form of:

- Reduced emissions to air as carbon dioxide (greenhouse) gas emissions.
- Reduced depletion of natural resources (fossil fuels and materials) as a result of the electrical energy expected from solid waste (WtE), which substitutes the electricity generated from the traditional resources.
- Reduced emissions to water by leaching.
- Reduced land requirements for landfill.

The potential for the solid waste energy supply can be limited by the availability of raw materials, one of the characteristics of any renewable energy. Solid waste energy recovery has contributed to global and local reductions in greenhouse emissions. The contribution of solid waste as a renewable energy, on a par with other renewable technologies, will continue to increase, despite the challenges it is facing, especially if WtE technologies integrate with recycling and re-use activities in the reduction of waste generation and disposal.

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REFERENCES

[1] Leone S. 2011. Renewable Energy World (www.renewableenergyworld.com).

[2] Sawin J. L. and E. Martinot E. 2010. REN 21, Renewable Global Status Report.

[3] International Energy Agency. 2012. Pathways to a Clean Energy System. Energy Technology Perspectives.

[4] Jacobson M. Z. and Delucchi M. A. 2011. Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. Energy Policy. 39: 1154-1169.

[5] International Energy Agency. 2007. Renewable in global energy supply, an IEA facts sheet: 3.

[6] Jupe S. C. E, Michiorri A. and Taylor P. C. 2007. Increasing the energy yield of generation from new and renewable energy sources. Renewable Energy. 14.

[7] Chandrappa R. and Das D. B. 2012. Solid Waste Management, Environmental Science and Engineering. Springer-Verlag Berlin Heidelberg.

[8] USA Environmental Protection Agency. 2008. Summary of the EPA Municipal Solid Waste Program. Environmental Protection Agency (http://www.epa.gov/reg3wcmd/solidwastesummary.htm).

[9] Hoornweg D. and Bhada-Tata P. 2012. What a waste, A Global Review of Solid Waste Management. Urban Development Series Knowledge Papers: 15.

[10] Pipatti R., Sharma C., Yamada M., Alves J. W. S., Gao Q., Guendehou G. H. S., Koch M., Cabrera C. L., Mareckova K., Oonk H., Scheehle E., Smith A., Svardal P. and Vieira S. M. M. 2006. IPCC Guidelines for National Greenhouse Inventories. 5: chap. 2.

[11] PAHO's Regional Evaluation of Solid Waste Management. 2005.

[12] Scheinberg A., Wilson D. C. and Rodic L. 2010. Solid Waste Management in the World's Cities. 3rd edition in UN-Habitat's State of Water and Sanitation in the World's Cities Series. Published by Earthscan for UN-Habitat.

[13] Van de Klundert A. and Anschütz J. 1999. Integrated Sustainable Waste Management -the Concept. WASTE, Gouda.

[14] Shah K. L. 1999. Basics of Solid and Hazardous Waste Management Technology. New Jersey: Prentice Hall, World Bank What a Waste: Solid Waste Management in Asia (www.worldbank.org/urban/solid_wm/erm/CWG%20folder/uwp1.pdf).

[15] Hickman and Lanier H. 2001. A Brief History of Solid Waste Management during the Last 50 Years", MSW Management.

[16] Wilson D. C., Rodic L., Scheinberg A. and Alabaster G. 2010. Comparative analysis of solid waste management in cities around the world. Proceedings Waste 2010: Waste and Resource Management - Putting Strategy into Practice. Stratford-upon-Avon.

[17] Tomberlin G. and Moorman B. 2004. Energy generation through the combustion of municipal solid waste. IEEE Power Engineering Society general meeting. 2: 1663-1664.

[18] Themelis N. J. 2003. Waste Management World. Review Issue: 40-77.

[19] European Union, Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. Official Journal of the European Communities. L182/1-19.

[20] International Solid Wastes Association, Energy from Waste, State-of-the Art Report (www.wte.org).

[21] Kiser J., Jonathan V. L. and Zannes M. 2002. The IWSA Directory of Waste-to-Energy Plants. Integrated Waste Service Association, Washington DC., USA.

[22] Tchobanoglous G., Theisen H. and Vigil S. 1993. Integrated Solid Waste Management. McGraw-Hill. New York, USA.

[23] Promotion of renewable energy, energy efficiency and greenhouse gas abatement (prega). Bangladesh Dhaka city solid waste to Electric energy project, A pre-feasibility study report prepared by the prega national technical experts from Bangladesh centre for advanced Studies.

[24] http://www.chinacsr.com/en/2008/.

[25] http://www.city.osaka.lg.jp.

[26] http://www.centrovolta.it/laviadellenergia/inglese/produzione/brescia

[27] International Energy Agency, Scenarios and Strategies to 2050 Energy Technology Perspectives. IEA. 2006.

[28] Khulna City Solid Waste for Electricity Generation A Pre-Feasibility Study Report.

[29] Ramsey/Washington County Resource Recovery Project. Updated Research Study: Gasification, Plasma, Ethanol, and Anaerobic Digestion Waste Processing Technologies. Forth Infrastructure and Environment, LLC.

[30]Janet L. 2011. REN21 Renewables 2011: Global Status Report.

[31]EIA Methodology for Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy, 2007.

[32]Waste as a renewable source September, 2008 (http://www.alternative-energy-news.info/technology/environment-wildlife/).

[33]Understanding Green Energy. 2011. The Definition of Renewable Energy (http://www.going-green-challenge.com/definition-of-renewable-energy.html).

[34]Global Wind Map Shows Best Wind Farm Locations

[35]Union of Concerned Scientists. How Biomass Energy Works

[36]Turcotte D. L. and Schubert G. 2002. Geodynamics (2nd ed.). Cambridge, England, UK: Cambridge University Press. pp. 136-137.

[37]Nemzer J. 2001. Geothermal heating and cooling (http://www.geothermal.marin.org/).

[38]Environmental Protection Agency. 2008. Municipal Solid Waste in the United States (http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw07-rpt.pdf).

[39]Banar M., Cokaygil Z. and Ozkan A. 2009. Life cycle assessment of solid waste management options for Eskisehir, Turkey. Waste Management. 29: 54-62.

[40]Khoo H. H. 2009. Life cycle impact assessment of various conversion technologies. Waste Management. 29: 1892-1900.

[41]Abduli M. A., Naghib A., Yonesi M. and Akbari A. 2010. Life cycle assessment (LCA) of solid waste management strategies in Tehran: landfill and composting plus landfill, Environment Monitoring Assessment. 178(1-4): 487-498.

[42]Morris J. 2010. Bury or Burn North America MSW? LCAs Provide Answers for Climate Impacts and Carbon Neutral Power Potential. Environment Science Technology. 44: 7944-7949.

[43]IEA. 2003. Municipal Solid Waste and its Role in Sustainability a Position Paper Prepared by IEA Bioenergy.

[44]Deriziotis P. and Themelis N. J. 2003. Substance and perceptions of environmental impacts of dioxin emissions. Proceedings of the 11th North American Waste-to-Energy Conference. ASME International. Tampa.

[45]Jackson C. 2011. MEP Britain's Waste: the lessons we can learn from Europe.

[46]Kaldellis J. K. 2012. Multicriteria Analysis of Municipal Solid Wastes Energy Recovery Technologies in Greece. Global NEST Journal. 14: 225-234.

[47]Energy Information Administration. 2005. Average Heat Content of Selected Biomass Fuels. Renewable Energy Annual 2004. Washington DC., USA.

[48]Abdur R. M. 2011. Prospect of Electric Energy from Solid Wastes of Rajshahi City Corporation: A Metropolitan City in Bangladesh. 2nd International Conference on Environmental Engineering and Applications IPCBEE. 17.

[49]Sudhir J. K., Venkata K. S. and Rao P. V. V P. 2010. Waste to Energy: A Case Study of Iluru, A.P, India. International Journal of Environmental Science and Development. 1: 3.

[50]Garth J. and Kowal P. 1993. Resource Recovery, Turning Waste into Energy. Penn State Agricultural College Agricultural and Biological Engineering and Council for Solid Waste Solutions. University Park.

[51]Utah State University Recycling Centre Frequently Asked Questions (http://www.usu.edu/recycle/faq.htm).

[52]Elwan A., Arief Y. Z. Adzis Z. and Saad M. H. I. 2013. The viability of generating electricity by harnessing household garbage solid waste using life cycle assessment. The 4th International Conference on Electrical Engineering and Informatics (ICEEI 2013). Procedia Technology 8C(2013): 1255-1261.

[53]Saeed M. O., Hassan M. N. and Mujeebu M. A. 2009. Assessment of municipal solid waste generation and recyclable materials potential in Kuala Lumpur, Malaysia. Waste Management. Elsevier. 2: 2209-2213.

[54]Bahillo A. 2006. NOx and N_2O Emissions during Fluidized Bed Combustion of Leather Wastes. Journal of Energy Resources Technology. 128: 99-103.

[55]Environmental Protection Agency. Municipal Solid Waste in the United States: 2005 Facts and Figures (http://www.epa.gov/msw/msw99.htm).

[56]Malakahmad A. 2010. Solid Waste Characterization and Recycling Potential for University Technology PETRONAS Academic Buildings. American Journal of Environmental Sciences. 6: 422-427.