Environmental Energy and Economic Research (2017) 1(1):113-124
DOI 10.22097/eeer.2017.46461

Economic and Environmental Evaluation of Waste to Energy through Gasification; Case study: Tehran

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Received: 2 November 2016 /Accepted: 26 December 2016

Abstract
In spite of the past few decades, gasification of waste is being used in the developed countries. Reducing the space for landfill sites, producing fuel from waste, as well as avoiding negative impacts of landfilling, are of advantages of gasification. The research was aimed at feasibility study of application of Tehran municipal solid waste (MSW) gasification in addition to understanding the waste gasification as a stable and economic substitute for generating clean energy. On this basis, the researcher analyzed the required information through library research and by examining different types of available gasifiers in the developed countries. Firstly, the profitability of the project was assessed by using the net present value method and then, the cost-benefit analysis of the project was performed. In this study, three scenarios of the MSW landfilling and two gasification scenarios were analyzed. The research findings indicate that the gasification scenario is more economical than the landfill. Finally, the environmental analysis of all of the three scenarios was reviewed and considering the fact that the gasification scenarios are in line with the Fifth Economic Plan of the Islamic Republic of Iran, they can be proposed as the best scenarios. As to comparison of the two gasification scenarios, it was found out that considering the capacity of the waste produced in Tehran and the volume of the input waste of the two gasifiers and reduction of the operational costs of Termiska TPS Gasifier, the model of Termiska TPS Gasifier is a more suitable option for Tehran.

Keywords: Solid wastes, gasification, clean development mechanism (CDM), net present value, and cost-benefit.

Introduction
Nowadays supplying human energy is one of the main concerns of all governments and nations. Reduction of fossil fuel resources and their influence from political and economic crises, growing demand for energy and stringent environmental regulations has beset the governments with serious challenges. Therefore, it is necessary for researchers to find methods to harness energies and optimize old energy production and consumption methods.

On the other hand, by emission of contaminant material resulted from combustion of fossil fuels which causes destruction of ozone layer and global warming, the world is experiencing growing changes. In this regard, landfills are of the main reasons for methane emission due to

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human factors. Hence, using waste and biomass as a fuel and generating energy from them not only reduces fossil fuel consumption, but also reduces methane production due to need for less landfills. For this purpose, gasification is considered as one of the methods. Pasandidefard et al (2007)

Discarding the fact that large quantity of municipal solid waste (MSW) is a great concern in many cities, landfills are the primary means of MSW disposal which is approximately taking 60% of the residential garbage generated in US, SCS (1989-1990). However, rising landfill tipping fees and their proven negative environmental impacts Denison (1996), have led to the search for cleaner and less costly alternatives for municipal waste disposal. High temperature energy recovery from MSW, known as waste-to-energy (WTE), is one alternative.

Waste-to-energy technologies are considered as one of the key waste treatment technologies due to their energy and heat recovery efficiencies from the waste. A number of research studies were accomplished to understand the potential environmental burdens from emerging waste treatment technologies such as pyrolysis–gasification (PG), Zaman, (2013).

The gasification is one of the old methods in development. This process was used extensively from the mid 1800's to the early 1900's to produce gas from the coal to heat and generate electricity. The second development occurred during the World War II in which natural gas replaced municipal gas. However, the need for liquid fuels has made the German engineers to innovate a new liquid fuel from the coal, Porsche et al. (2007).

Given the fact that gasification is rarely employed in waste management of developing countries, this article attempts at studying gasification and its methods as a solution to reduce pollution, increase efficiency of refineries, plants and industrial units, and finally to optimize the existing capacities in gasification and expand them. About 710 kWh electricity can be produced from treated municipal solid waste through gasification, while there is no reasonable income from MSW landfills in our case study region, Kamalan et al. (2012). This study was carried out during 2011 upto early 2013 in Iran, Tehran.

Material and Methods

Gasification

The gasification is a thermo-chemical process in which materials with organic or fossil origin are converted to carbon monoxide, hydrogen, carbon dioxide, and methane. This process is initiated at 700°C with tiny amount of oxygen and vapor in a controlled manner without combustion taking place. The gas obtained from this method is called syngas (synthesis gas or artificial gas). Energy from gasification is considered a renewable. Gasification of fossil fuel derived from plastic material is not considered renewable. In gasification, discarded bio-waste can begin the process as input material, National Non-Food Crops Center (2007).

In gasification, two stages are considered to produce a usable fuel gas. In the first stage, decomposition and freeing of super fuel components occur in a temperature lower than 600°C. The by-product of method that is not vaporized is called char and consists mainly of fixed carbon and ash. In the second gasification stage, the carbon remaining after pyrolysis is either reacted with steam or hydrogen or combusted with air or pure oxygen, Belgiorno et al. (2002). Gasification with air results in a nitrogen-rich, low BTU fuel gas. Gasification with pure oxygen results in a higher quality mixture of carbon monoxide and hydrogen and virtually no nitrogen. Gasification with steam is more commonly called "reforming" and results in a hydrogen and carbon dioxide rich "synthetic" gas (syngas) Volkman (2004). In total, the reaction between oxygen and carbon is exothermic and provides the necessary energy to expedite the decomposition and carbonization processes, Eren (2002).Gasification technology has the following characteristics:

I. The ability to produce a product which can be employed to generate either electricity and be used as a primary material to produce chemical material or fuels.
II. The ability to produce a wide spectrum of materials including char, heavy oil, and heavy refinery material, refinery wastes (solid, liquid), and farming wastes and biomass.
III. The ability to remove pollutants from primary materials, and production of clean gas products (synthesis gas).
IV. The ability to convert waste materials to valuable products.

A large number of gasification reactions may occur. In total, there are three independent gasification reactions. Depending on the type of gasification process, the reactions occurring in a gasification process are presented in table 1. This is a simplified scheme, since other components (H, N, O, S, etc.) can play a role as reactants or products. Most gasification processes are reduction processes with lower oxidation numbers, such as CO instead of CO_2 or H_2 instead of H_2O and for other elements, H_2S instead of SO_2, NH_3 or HCN instead of NO or other oxides. Furthermore, the absence of oxidant elements in one of the stages of dioxin synthesis reduces its formation rate significantly. All gasification reactions, except oxidations, are reversible.

Table 1. Main reactions of homogeneous and non-homogeneous phases during gasification of municipal waste material, Klein (2002) and Arena (2011)

	Oxidation reactions		
I	$C+\frac{1}{2}O_2 \rightarrow CO$	(-111) MJ/Kmol	Oxidation of carbon derivatives
II	$CO+\frac{1}{2}O_2 \rightarrow CO_2$	(- 283) MJ/Kmol	Oxidation of carbon monoxide
III	$C+O \rightarrow CO_2$	(- 394) MJ/Kmol	Oxidation of carbon
IV	$H_2+\frac{1}{2}O_2 \rightarrow H_2O$	(-242) MJ/Kmol	Oxidation of hydrogen
V	$C_nH_m + {}^{n}/2O_2 \leftrightarrow nCO+m/2H_2$	exothermic	Oxidation of C_nH_m derivatives
	Gasification reactions relatedto the vapor		
VI	$C+H_2O \leftrightarrow CO+H_2$	(+131) MJ/Kmol	Water-gas reaction
VII	$CO+H_2O \leftrightarrow CO_2+H_2$	(-41) MJ/Kmol	Water-gas reverse reaction
VIII	$CH_4+H_2O \leftrightarrow CO+3H_2$	(+206) MJ/Kmol	Phase change of vapor-methane
IX	$C_nH_m +nH_2O \leftrightarrow nCO+(n+m/2)H_2$	endothermic	Vapor phase change
	Gasification reactions related to hydrogen		
X	$C+2H_2 \leftrightarrow CH_4$	(- 75) MJ/Kmol	Hydraulic gasification
XI	$Co+3H_2 \leftrightarrow CH_4+H_2O$	(- 227) MJ/Kmol	Methane-generation
	Gasification relations related to carbon dioxide		
XII	$C+CO_2 \leftrightarrow 2CO$	(+172) MJ/Kmol	Boudouard reaction
XIII	$C_nH_m +nCO_2 \leftrightarrow 2nCO+m/2H_2$	endothermic	Dry phase change
	Reactions to the decomposition of tar and hydrocarbons		
XIV	$pC_xH_y \rightarrow qC_nH_m+rH_2$	endothermic	Dehydration
XV	$C_nH_m \rightarrow nC+m/2H_2$	endothermic	Carbonization

The following physical, chemical and thermal processes can occur successively or simultaneously based on the reactor design and primary materials:

I. Drying occurs at 100°C. Conventionally, the vapor is combined by the gas flow and participates in later reactions especially water and gas reaction in case the temperature is sufficiently high.
II. Volatilization and separation of volatile materials depending on the combination and structure of initial material occurs 200-300°C. Volatile gases can include C_2H_6, NH_3, H_2S, CH_4, CO, O_2, N_2, H_2, H_2O, and a tiny amount of unsaturated hydrocarbons.
III. Combustion: the heat required for gasification reactions should be directly provided by the combustion of a part of char, initial material, or volatile gases or should be indirectly introduced into the gasifier.

IV. Gasification processes: gasification is the result of chemical reactions between the carbon in the coal and vapor, carbon dioxide, hydrogen in the ducts of the gasifier, also the reaction between the gases from the preceding stages.
The purpose of gasification process is the conversion of primary materials to valuable intermediate products which can be utilized as fuels, chemical materials and for production of energy, National Non-Food Crops Center (2007).

Types of gasifiers and their design

Fixed bed gasifiers (updraft & downdraft)

In gasification by fixed bed, there is a deep bed of waste which can fill the full volume of the reactor and various regions with a definite succession and order which depends upon the average waste flow direction. They have two types: updraft and downdraft. In the updraft system, the waste is charged from upper part of the gasifier and the oxygen from below. In this method, the waste goes through a gas stream and passes various regions by different methods (drying, decomposition due to temperature, oxidation and regeneration). The fuel is dried above the gasifier such that waste with high humidity can be used. Methane, tar, and rich gas are removed from the upper section and ash is collected in the lower section. In the downdraft system the waste enters from the upper section, while the oxygen enters from the upper part or from two sides; then the gas and the waste flow in one direction, Di Blasi (2000). Conversely, in the updraft system, they flow in opposite directions. A portion of the waste is incinerated and the remaining enters the bed from the throttle, and after these materials pass through hot ash surface, gas is produced. This results in production of syngas with a fairly high quality (with relatively low tar content) which gathers in the lower section of the gasifier with ash. The air flows perpendicular to the vertical axis of the kiln in downdraft gasifier system, which is referred to as "direct melting system" by Nippon Steel. It is a high temperature gasification and melting process, with O2-enriched air injection in the melting section (at 36% of O2concentration), which directly evolved from metallurgical processing technology. Steel claims power generation from about 400 kWh/t MSW (when MSW is co-gasified with bottom ash discharged from other MSW incinerators and with combustible and incombustible residues from recycling centers) to about 670 kWh/tMSW (when only MSW is gasified), depending on the feedstock properties (LHV and ash content, which causes higher sensible heat of melt) and boiler system, Herman et al. (2001) and Hankalin (2010) and Arena (2011).

Bubbling and circulating fluidized bed gasifiers (BFB & CFB)

In this type of gasifier, gas (air, oxygen, or oxygen-rich air) flows upwards from air distributor plate and neutral material (usually silicon or chrysolite) usually containing wastes which diffuses the gasifier from below. Superficial gas velocity is defined as the ratio of gas volumetric flow rate and the cross-sectional area and it is approximately 1m/s which is several times greater than the minimum fluidization velocity which creates tensile force between particles which is equal to the particle's weight in the bed and acts similar to liquid. This fluid-like state produces an intense mixing and gas-solid contact that allow very high temperature and mass transfers. All the main properties of the system are strongly related to the crucial role that hydrodynamics plays in the design and operations of a fluidized bed. Moving parts are not present inside the rotor; thus its maintenance is easy. The generated syngas moves upwards and leaves the reactor. This operates at a temperature under 900°C to prevent melting of the ashes. When the gas surface velocity increases, the velocity of solid materials moving out of the gasifier also increases (usually to higher than 3 m/s), Hankalin (2010) and Arena (2011).

Entrained flow gasifiers

These gasifiers operate at higher pressures, approximately 25 bars. They are used to treat coal, but also refinery residues and mixed plastic waste, because they can be slurried to make solid fuel feeding at high pressures inexpensive and have an energy content high enough to sustain the gasification reaction (with the addition of a supplementary fuel if necessary). In this gasifier, micro-fuel particles (with diameter less than 1 mm, which are usually obtained by grinders) are added to water to produce grout with total solid concentration greater than 60%. Water acts as a temperature controller and also as a reactor in formation of hydrogen. Grout is fed to the gasifier with oxygen (or air) to rapidly convert the waste with high quality to syngas. The produced ash is poured on the gasifier wall as a molten slag to cool the metals, NETL-U.S (1995) and Arena (2011).

Rotary kiln gasifiers

This reactor is used for various programs, such as incineration of industrial waste from cement production. The concept of rotary kiln achieves two purposes at the same time: Movement of solid particles inside and outside the reaction area in high temperature and mixing of solid materials during the reaction. The kiln is usually made of durable and fireproof cylinder to prevent corrosion of metals. The movement of solid materials is controlled to be 1.5 revolutions per minute. The waste materials are gasified at the temperature of 450°C in a drum, and they are converted to gas and ash. After separation and recycling of aluminum, iron and other wastes are charged and incinerated at high temperatures. At 1300°C and low excess air ratio (approximately 1.2), the ash melts and is converted to slag, Grimshaw et al. (2010) and Arena (2011).

Plasma gasifier

The waste is reduced due to recycling and then enters the gasifier. The bed of this type of gasifier is frequently moving. Electric plasma is produced in atmospheric pressure and at the temperature between 1500°C - 5000°C and organic material is converted to syngas with high quality and mineral material is converted to slag. Even though plasma is typically used to valorize solid wastes in a single-stage process, there is also a quite different, two-stage approach. The first stage utilizes a conventional gasifier while the second plasma stage is used to reduce the tar content in the syngas and increase the conversion efficiency, Juniper (2000).

The costs and benefits of gasification

The total investment cost for a gasification factory in the smallest economic scale is estimated to be $271-306 per tonne of municipal solid waste each year. Except the initial processing, other processes differ significantly. The operational costs for gasification plants start from $41.4 to $55.2 per one tonne of municipal solid waste without considering the costs concerning the wastes, Niessen et al (1996). Given the net work and the costs related to consumables (for instance, chemical materials, bed materials) whose information is presented in table 2, for two gasifiers the costs would significantly differ (TPS Termiska and Batelle Colombus) Kelin (2002).

Investment cost per one tonne of municipal solid waste is obtained by dividing the total investment cost into yearly input waste. Operational cost per one tonne of municipal solid waste is obtained by dividing the total operational cost into yearly input waste.

The benefits of gasification include the production of fuel, chemical materials and generating energy. In this study, the benefits related to electricity generation, and reduction of carbon emission is considered between 97.43 and101.25 $ per tonne of municipal solid waste annually. The information regarding two gasifiers under this study (TPS Termiska and Colombus Batelle) is presented in table 3, Alizadeh (a) et al. (2013).

Table 2. Precise analysis of investment and operational costs per one tonne of municipal solid waste the mentioned cost data are based on Klein's studies in (2002)

Investment costs	TPS Termiska ($)	Batelle Colombus ($)
Inlet waste (tonne per year)	642,400	341,275
Processing/grinding costs	72,220,000	42,550,000
Gas refinery and engineering costs	65,406,250	14,411,800
Electricity and production costs	58,650,000	35,650,000
Total investment cost	196,276,250	92,611,800
Investment costs per one tonne of municipal solid waste	305.54	271.37
Operational costs		
Work, management, reparation and maintenance	11,820,160	6,671,926
RDF processing process	5,910,080	3,532,196
Waste disposal costs	8,865,120	8,634,258
Total yearly operational costs	26,595,360	18,838,380
Operational costs per one tonne of municipal solid waste	55.2	41.4

Table 3. Outlet and inlet power of gasifiers kWh

Inlet/outlet power	TPS Termiska	Batelle Colombus
Yearly generated electricity	781	703
Electricity for RDF process	130	70
Electricity for gasification process	15	21
Extra electricity for sale	636	612

Benefits of selling generated electricity are 64.55$ and 62.12$ per tonne of municipal solid waste in the two gasifiers, respectively. With this relation, they calculate the external costs regarding the environment. Earlier, they reached the conclusion that 0.0577 $ is the cost related to environmental costs for 1 kWh of electricity. Thus, environmental costs of 36.70$ and 35.31$ per each tonne of municipal solid waste for the two gasifiers are undeniable, Alizadeh (a) et al. (2013).

Municipal waste landfills

Municipal solid waste landfill can represent a source of main environmental impacts closely linked to the potential emission of leachate and landfill gas, which may cause groundwater pollution, soil contamination and global warming effects (Pantin et al., 2013). Tehran's daily waste production reaches 7500 tonnes. The wastes contain kitchen redundant material, electronic appliances, lamps, plastic, rubber, old paints and yard wastes. Even though the recycling has expanded, approximately one third of municipal waste is recycled and the remaining is buried or incinerated in the landfills. However, these traditional waste disposal methods are converting to durable and economic processes. According to analyses, approximately 65% is organic material and the remaining (35%) is dry waste. Only a small portion of municipal solid wastes, which is metals and glasses, cannot be used in gasification. Textiles, rubbers-especially old ones and all types of plastics can be gasified on the condition that suitable clean gas is employed, Harati (2009).

In many countries, waste incineration is banned due to its adverse environmental effects. In the US, a number of states such as New York, New Jersey, Massachusetts, Connecticut, and California have faced lack of landfills, and they are obligated to transfer their solid waste thousands of miles to be buried in other countries. In addition to the use of valuable fields, decomposition of municipal solid wastes, production of methane, as a greenhouse gas, and leachate threatens surface and underground waters.

To solve the million-dollar problem of landfill, a large number of municipalities have turned to gasification. This method is environmentally friendly and converts the energy inside the waste to beneficial products such as electricity, fertilizers, transportation fuels, and chemical materials. By incinerating one tonne of waste, we can generate 550 kWh energy on the average, Vadillo and etal (1994).

Cost and revenue of municipal landfills

For this study, the landfill is considered for a 20 years period. The time scheme for closing is estimated to be 10 years after the end of waste burying operations. Gas emission remains approximately constant after 20 years, Johari et al. (2010).

It should be emphasized that the estimation of investment costs has been conducted based on the assumption that the landfill consists of clayey soil with small permeability and as a result synthetic flooring or geo-membrane is not needed. Otherwise, it is estimated that the total costs increase from 80 to 150 percent due to high costs of synthetic flooring. The costs and benefits necessary for one tonne of waste is presented in table 4, Alizadeh(b) et al. (2013).

Table 4.summary of costs and revenues of landfill ($/ton of MSW) BC Berlin (2004)

Types of costs	$/ton
Yearly investment costs	10
Yearly operational costs	200
Methane emission from municipal landfills	0.14
Carbon dioxide emission from municipal landfills	0.09
Types of benefits	$/ton
Clean development mechanism	0.33

Social costs

Social cost is defined as the cost which estimates the destructive effects of a pollutant or activity on farming crops, ecosystem, material and human health and it is usually not considered in the ultimate price is presented in table 5. In another definition, the cost which can compensate the damages from emission of pollutants and greenhouse gases is called destruction cost or social cost. To calculate destruction costs, it is needed to quantify the effects of pollutants and activities in the influenced environment (human and natural), Ministry of energy, energy convention, (2008).

Table 5. The values of profits from pollutant reduction for Iran, Shafipour et al (2005)

Pollutant	Value (dollars per tonne)
NOx	600
SO_2	1.825
CH_4	210
CO_2	10

Economic analysis

In the economic section, the aim is to determine the costs and benefits for each plan during its lifetime and to select the most economic technology. Inasmuch as various technologies have various characteristics (longevity, performance, cost, etc.), it is necessary to employ an economic technique by considering time value of money. Engineering economics techniques are: Benefit to cost Method, present worth method, equivalent uniform annual cost (benefit), rate of return method, return on investment (ROI), payback period, profitability index (PI), total cash inflow and outflow, and other techniques, Oskounejad (2010). Various factors influence the feasibility of optimization projects. Utilization, maintenance and financial costs of the project are of the key factors. First, by using net present value, all the cost and revenues are obtained with a proper interest rate according to the time they occur using the following equation.

$$R_t / (1+i)^t \qquad (1)$$

In the equation above, t is the time in which the cost or revenue occurs, i stands for the interest rate (product of profit rate, risk rate, and predictable inflation rate) and Rt is the quantitative value of the revenue or cost according to the cash flow. By subtraction of converted costs from converted revenues a number will be obtained which is called net present value. If this number is positive, the plan is profitable and acceptable and in case it is negative, the plan is unprofitable and inapplicable (from economic point of view). Since there are costs and revenues during a plan's life of various technologies, we primarily calculate the annual flat fee for each plan by using net present value method. Inasmuch as we aim at comparing the negative aspects of the technologies to the environment; this means that as the number is greater, the technology is more environmentally destructive. Then to obtain the net profit of the plans, the income and cost of the plan is discounted for 20 years and the addition is obtained. In other words, the net present value of costs and revenues is obtained for each plan.

Then the net present value of the revenue is divided by the net present value of the costs, so that net profit is obtained. If the number is greater than zero the project is economical. In this study, the costs include: Initial investment cost, utilization and maintenance, operations, fuel cost, and pollution cost and the revenue include: The revenue from clean development mechanism (CDM) and the price of electricity from different technologies. By obtaining the addition of costs and benefits and using the cost-benefit method, superior plan is chosen, Oskounejad (2010).

Environmental analysis

Environmental analysis of the process is the examinations and studies in order to predict the effects of activities and operations of a project on the environment, human health, social welfare or, in other words, identification and systematic evaluation of the consequences of projects, programs, and plans on physical, chemical, biological, cultural, economic, and social components of the environment. Hence, environmental analysis, as a tool of scheduling, determines the positive and negative effects of a project on the environment. For environmental analysis of various electricity-generating technologies, it is acted as follows: First by using the existing resources and the conducted studies, environmental parameters influenced from both plans (landfill, gasification) are identified. Then the environmental costs of all parameters influenced from energy generation are supplied for various plans, Monavari (2002).

Results and Discussion

Climatic change and global warming are of the environmental problems all countries, Akhgari and Kamalan (2012). Emission of greenhouse gases whose considerable volumes enter the atmosphere from the landfills have caused many developed countries to manage and extract these gases and use them as renewable energy sources, Sabour and Kamalan (2009). One of the great crises that the world has encountered is the climatic change and consequently, the developed countries face the most harms and threats. The earth is becoming warmer and warmer each day. One of the main reasons is the climatic changes. Societies and governments need to introduce direct or flexible laws before the conditions reach the irreversible point. At the moment, municipal waste management in Iran is based on landfill. Non-engineering landfill has caused many environmental negative impacts such as the destruction of the environment, reduction of general hygiene, socioeconomic impacts, emission of methane, carbon dioxide, nitrogen, hydrogen, and other harmful gases. Solid waste which has undergone biological degradation, and in the phase of mechanization the large amounts of gas (55% methane and 45% carbon dioxide) are released. Gas Sim calculations show about 6 million tons of carbon dioxide gas out of its total amount. Emissions of methane from landfills is 22-46 Tg/y million tons per year and the average is 34 Tg/y or between 6-13 percent of total emitted methane entirely, Scharff et al. (2006). Based on Kyoto Protocol six types of gases, including carbon dioxide and methane, are classified as hazard, Atabi (2009). Methane is the most principal gas produced by decomposition of the waste in the landfills. In case the methane is not controlled, it will have detrimental environmental effects. Hence, gas management system in landfills is a necessity. By choosing the correct decision in selecting the optimum method, the risk of gas emission into the environment, landfill explosion, and fire are considerably reduced.

In this study, in addition to introduction of gasification process and its characteristics, various types of gasifier reactors and their advantages and disadvantages especially in the field of increasing efficiency of clean energy generation and reduction in the production of environmental pollutants are examined. The results clearly indicate the practicality of gasifier applications or solid gasification cycles in micro and macro industries of Iran. Reasons such as the low efficiency of electric energy generation in the plants or high volume of kiln oil production in the refineries are undeniable. However, presentation of numbers even approximate from the capital and ability necessary to create and develop gasifying units in Iran has not received adequate attention. The reason is that gasification in Iran has not gone beyond theory and the studies and calculations are very few and they are not adopted on practical samples at universities and research centers. It is obvious that its future depends on the policy-makers and private and public sector capitalists who by creating the ground can make a great difference in the provision and guarantee of the country's energy. Given the type and high humidity of Tehran's waste (70%) and based on the advantages and disadvantages of various gasifiers, circulating fluidized bed and bubbling gasifiers are suitable due to their high efficiency and their high inlet humidity (up to 55%), design for large scales (waste produced in Tehran is 7500 tonnes per day; 30% is recycled. So, 70% (5250 tonnes) can be gasified daily) and their simpler design and cheapness. The costs and benefits depend upon the gasifier design and their wastes management capacity. Two gasifiers of TPS Termiska and Colombus Batelle are considered as the technologies for cost and benefit study since they are more extensively used. They have the ability to convert municipal waste to energy in large scales. The gasifier TPS Termiska is manufactured as by a Swedish company to gasify solid material. This is selected by the World Bank as the first commercial electricity plant using municipal solid waste. The factory is now located in Bahia state in Northeastern Brazil. The data on TPS Termiska and Columbus Batelle is based on the data from scale test published by national laboratory for renewable energies. The TPS Termiska includes two systems of circulating bed with downstream which include dolomite for breaking tar and one combined cycle turbine. Batelle system includes circulating bed system which is mixed and heated by water vapor which is in conjunction with the system for combustion of sand with the fluid air. Batelle factory is for generation of electricity with multiple turbine cycle.

Based on the presented information, better utilization of gasification is in the conversion of waste to electricity. Batelle gasifier generates more valuable product compared with the TPS. It does not allow nitrogen to enter its channels due to its indirect heating. Hence, the volume of gas produced in this type of gasifier is considerably lower than all other plants. The gas capacity of TPS Termiska can be up to 642,400 tonnes per year. The TPS technology without air uses the bubbling and circulating bed gas processes at 850°C and roughly at the atmospheric pressure. Yearly capacity of Colombus Batelle is 341,275 tonnes of municipal solid waste. Gasification is conducted with circulating bed by indirect heat at atmospheric pressure. The benefits of gasification are fuels, chemical materials and energy generation. In this study, special benefits—electricity generation and reduction of carbon dioxide—are considered. Colombus Batelle has the ability to generate 703 kWh per one tonne of processed municipal solid waste and the TPS can generate 718 kWh per one tonne of processed municipal solid waste.

Data for each technology is such that for landfills, investment cost of $10 for each tonne of TPS Termiska 305.54$ and for Colombus Batelle, 305.54$ are required. The operational costs for municipal landfill is 2$ for one tonne, for the TPS Termiska is 41.40$ and for Colombus Batelle is 55.20$. In addition to investment and operational costs, the social costs of methane production is 0.145$ and that of CO2 production is 0.09$ and the cost of carbon emission from gasification for the TPS Termiska and Batelle Colombus is 4$ per one tonne.

The revenue earned from reduction in methane emission or electricity generation for municipal waste landfill is 0.336$ for each tonne, for TPS Termiska gasifier: 64.55$, and for Batelle Colombus yearly: 62.12$. The revenue from clean development mechanism (CDM) for landfills is zero due to absence of hygienic burial conditions, and for gasifier TPS Termiska: 36.7$ and for Batelle Colombus: 35.31$ for each tonne.

To normalize the data and obtain the net present value, the costs and benefits were discounted by discount rate of 25% for 20 years. Then to obtain cost-benefit ratio, the costs and benefits are also discounted for 20 years.Concerning net present value, we can state that if this number is positive, the plan is profitable and acceptable and if it is negative, the plan is unprofitable and inapplicable (from economic point of view). In total, elimination of municipal waste is an uneconomical plan; thus we seek a better choice. Finally, the revenue cost ratio was obtained which was 0.07 for municipal landfills, which is approximately zero, and 0.79 and 0.85 for TPS Termiska and Batelle Colombus respectively which is approximately one. As stated before, in case cost-benefit ratio is more than 1, the plan is economical; otherwise it is uneconomical. Therefore, we conclude that gasification plan is more economical compared with landfill. Ultimately, environmental analysis was conducted on the three plans and given the fact that gasification plan is in line with the fifth development plan, it is chosen as the superior plan.

Concerning environmental aspects, based on the fifth development law which analyzes environmental programs, between the three considered plans and given the environmental pollutions caused by landfills, gasification plans are in line with the fifth development law. Concerning the two gasification plans, given the waste produced in Tehran1,916,250 tonnes per year can by gasified or buried. The capacity of TPS Termiska gasifier is 642,200 tonnes per year and that of Batelle Colombus is 341,275 tonnes per year. Thus, given the waste production capacity in Tehran and the capacity of the two gasifiers and the reduction of operational costs, the TPS Termiska gasifier is a more suitable choice for Tehran.

Acknowledgements

The authors wish to acknowledge research deputy of Islamic Azad University, Science and Reaserch branch for supporting the study, Seyed Mehdi Jafari for helping to editing and Renewable Energy Organization (SUNA) and Tehran Waste Management Organization (TWMO) for helping to data treatment. We thank from Seyed Masud Monavari and Seyed Amirnaser Harati for their constructive and insightful comments on the manuscript.

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