Energy Conversion and Management 103 (2015) 321–337

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Techno-economic analysis of municipal solid waste gasification for electricity generation in Brazil

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ARTICLE INFO

Article history:
Received 27 February 2015
Accepted 25 June 2015
Available online 3 July 2015

Keywords:
Municipal solid waste
Gasification
Synthesis gas
Techno-economic analysis
Waste-to-energy
Renewable energy

ABSTRACT

The key objective of this paper is to analyze the techno-economic feasibility of this alternative for the Brazilian municipalities, classified according to population subgroups, using this parameter as a basis for the calculation of the municipal solid waste generated, the project costs and revenues. Different expenses were taken into consideration, like equipments and installation costs, operation and maintenance costs and the interest rate of the investment. In relation to revenues, they come from of the sale of electricity, the incomes of the recyclable materials, the fees paid by the Brazilian municipalities for the disposal of municipal solid waste in sanitary landfills and incomes by the carbon credits. An analysis of each population subgroup, combining three different economical scenarios was done, with an annual rate of interests of 10.58% for Scenario 1, 7.5% for Scenario 2 and 15% for Scenario 3. The economic feasibility was evaluated using as economic indicators the net present value and the internal rate of return. The net present value was positive for the municipalities with more than 60,714 inhabitants for the Scenario 1, 34,203 for Scenario 2 and 259,845 for Scenario 3. A hypothetic gasification plant is capable to generate 905 kW/ton municipal solid waste for a population of 60,714 inhabitants (Scenario 1), 794 kW/ton municipal solid waste for a population of 34,203 inhabitants (Scenario 2) and 1065 kW/ton municipal solid waste for a population of 259,845 inhabitants (Scenario 3). It is concluded that the economic feasibility increases with the installation of bigger units, showing a positive scale up gains, therefore as higher the capacity of the installation lower the specific costs and higher are the benefits.

1. Introduction

Growing problems of the treatment and disposal of agricultural wastes, industrial wastes and Municipal Solid Wastes (MSW), crescent concerns for human and environmental well-being and dwindling reserves of fossil fuels, have led to research into the potential of utilizing appropriate technologies to recover energy and useful by-products from domestic and industrial solid wastes [1]. However, to determine the optimum route of biofuels and electricity production [2] and wastes conversion into energy should be carried out an analysis of the environmental impact assessment [3,4].

MSW landfills represent the dominant option for waste disposal in many parts of the world. In general, the comparatively high costs of treatment and disposal alternatives are a major reason for the reliance on MSW landfills [5]. Nevertheless, even some highly industrialized countries largely depend on landfilling. It has been pointed out the spectacular increase of the amount of MSW that must be treated and disposed, that currently, it is becoming the main issue of MSW management. In the future the quantity of MSW will be much higher than today [6].

Brazil is the 7th world economy and the biggest country in Latin America, its population (204 million inhabitants) generates more than 208,000 tons MSW/day. About 70% of the municipalities have less than 20 thousand inhabitants, in contrast to the 15 largest metropolitan regions that have 37% of the population, corresponding to 72 million inhabitants. The average MSW per capita generation was 1.15 kg MSW/person/day. The collection of MSW from

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http://dx.doi.org/10.1016/j.enconman.2015.06.074
0196-8904/

Nomenclature

Abbreviations

CCE	Carbon Conversion Efficiency
CCEE	Chamber for Commercialization of Electrical Energy
CEMPRE	Brazilian Business Commitment for Recycling
CGC	Cold Gas Cleaning
CGE	Cold Gas Efficiency
CUF	Capacity Utilization Factor
FGTS	Guarantee Fund for Length of Service
HGC	Hot Gas Cleaning
HHV	Higher Heating Value
IC	Installation Costs
ICE	Internal Combustion Engine
INSS	National Social Security Institute
LFG	Landfill Gas
LHV	Lower Heating Value
MSW	Municipal Solid Waste
NPSW	National Policy on Solid Waste
NPV	Net Present Value
O&M	Operation and Maintenance
RDF	Refuse Derived Fuel
SELIC	Settlement and Custody Rate
SOFC	Solid Oxide Fuel Cell
SRF	Solid Recovered Fuel
Syngas	Synthesis Gas
WTB	Waste Treatment Bill
WtE	Waste-to-Energy

Latin symbols

C	costs ($)
CF	cash flow ($)
CUF	Capacity Utilization Factor (–)
E	Expenditures ($)
i	discount rate (%)
IRR	Internal Rate of Return ($)
m	mass of waste
MRA	Minimum Rate of Attractiveness
N	number (–)
NPV	Net Present Value ($)
P	power (kW)
Q	thermal energy (kW_{th})
R	Revenues ($)
t	lifetime of investment (years)

Greek symbols

η	efficiency (%)

Subscripts

atp	available thermal power
d.b.	dry basis
e	electrical energy
ecp	electric consumption of the process
ic	installation costs
ie	installed electrical power
lc	labor charges
m	maintenance costs
meq	maintenance costs of equipments
nsp	specific net electrical power
O	operation
ot	operation time
O&M	operation and maintenance costs
sal	salary
sne	specific net efficiency
SRF	Solid Recovered Fuel
syn	syngas
t	total
tdw	total of dry waste
th	thermal energy
w	workers
wf	workforce costs

homes has encompassed 98% of the urban population and 80% of the population of the whole country [7]. The mean costs of the MSW disposal in landfills ranges from $ 8.80/ton (in the landfills managed by the municipality) to $ 35.10/ton (in private landfills), these costs are lower than the ones of other technologies presently in use in the country and do not encourage the investment in such technologies [8].

Only recently Brazil has implemented its first policy instrument to manage the MSW, the Federal Law N° 12.305/2010 [9], establishing the National Policy on Solid Waste (NPSW), as regulated by Decree N° 7.404/2010 [10], which provides the principles, goals and instruments for the management of solid waste, including the responsibilities of producers and the local governments, the guide to the management of hazardous waste and the economic instruments to be applied for all the Brazilian municipalities for the dispose of their wastes in a safety way. The objective of the law is to get an integrated management of MSW, the reutilization and recycling of solid waste, including energy recovery systems [11].

There are two available technological routes for the energy recovery from MSW: biochemical and thermochemical. The biochemical route comprises the recovery of Landfill Gas (LFG) and its utilization as fuel in different type of power plants, such as gas turbine cycle, steam cycle, combined cycle, Internal Combustion Engine (ICE), Solid Oxide Fuel Cell (SOFC) [12], also the anaerobic digestion of MSW organic fraction, to generate biogas to be burned in the same type of power plants that have been related previously [13] and the thermochemical route that is the main point of this paper.

In the present paper, the attention is focused over the MSW energy recovery through thermochemical conversion technology; these forms of MSW management have more benefits than the landfill disposal. Thermal treatment plants can in fact convert the energy value of MSW into different forms of energy, such as electricity and process heat [14]. The main available thermochemical conversion processes, for MSW energy recovery, are: incineration (direct combustion), pyrolysis and gasification. In addition to the individual methods, combinations of these processes with other treatments are possible, for example, plasma gasification, melting, distillation, etc. [15].

Gasification of MSW is also a very appealing technology, but there are only a few demonstration-scale projects in the world [16]. Gasification is a partial oxidation at elevated temperature (600–1700 °C) that converts organic compounds in a Synthesis Gas (syngas), consisting mainly of CO, H_2, small amount of CH_4, minor quantities of different hydrocarbons (tars), inorganic impurities (H_2S, HCl, NH_3, HCN, HF, alkalis) and particulates [17]. A gasifier can use air, O_2, steam, CO_2 or a mixture of all these as gasification fluids. Air gasification produces a syngas with small Lower Heating Value (LHV) ranging from 4.0 to 6.0 MJ/Nm^3, while O_2 gasification produces a syngas with a medium LHV ranging from 10.0 to 20.0 MJ/Nm^3 [18].