# Economic and Environmental Benefits of Conversion of Municipal Solid Waste into Renewable energy: A Case Study of Islamabad


By

**Nazish Rafiq**

**Department of Environmental Economics**

**Pakistan Institute of Development Economics (PIDE)**

**Islamabad**


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By

**Nazish Rafiq**

Supervisor

**Dr. Zeshan**

**Assistant Professor**

**Institute of Environmental Sciences and Engineering (IESE)**

**National University of Science and Technology (NUST)**

**Islamabad**

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## CERTIFICATE

This is to certify that this thesis entitled: **"Economic and Environmental Benefit of Conversion of Municipal solid waste into Renewable Energy: A Case study of Islamabad".** submitted by Nazish Rafiq accepted in its present form by the Department of Environmental Economics, Pakistan Institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfillment of the degree in **Master of Philosophy in Environmental Economics**.

Supervisor:

Dr. Zeeshan Sheikh,
Assistant Professor
NUST, Islamabad.

External Examiner:

Dr. Abid Qaiyum Suleri,
(SDPI), Islamabad.

Head,
Department of Environmental Economics

Dr. Rehana Siddiqui
Head
Department of Environmental Economics

Dedicated to

**My Parents**

## CERTIFICATE

This is to certify that this thesis entitled **"Economic and Environmental Benefits of Conversion of Municipal Solid Waste into Renewable energy: A Case study of Islamabad"** submitted by Ms. Nazish Rafiq, is accepted in its present form by the Department of Environmental Economics, Pakistan institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfilment of the degree of Masters of Philosophy in Environmental Economics.

**Supervisor:**

____________________

**Dr. Zeshan**

Assistant Professor

Institute of Environmental Sciences and Engineering (IESE)

National University of Science and Technology (NUST)

Islamabad

**Head of Department of Environmental Economics:**

____________________

**Dr. Rehana Siddiqui**

Pakistan Institute of Development Economics (PIDE)

Islamabad

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# List of Abbreviations

| | |
|---|---|
| **MSW** | Municipal solid waste |
| **OFMSW** | Organic Fraction of Municipal Solid Waste |
| **AD** | Anaerobic digestion |
| **UNDP** | United Nation Development Programme |
| **IESCO** | Islamabad Electric Supply Company |
| **UNFCCC** | United Nation Framework Convention on Climate Change |
| **EPD** | Environment Protection Department |
| **CDA** | Central Development Authority |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **PCRET** | Pakistan Council of Renewable Energy Technology |
| **GHG** | Green House Gases |
| **NPV** | Net Present Value |
| **IRR** | Internal Rate of Return |
| **PBP** | Payback Period |
| **BCR** | Benefit Cost Ratio |
| $m_3$ | Cubic meter |
| **C** | Carbon |
| $CO_2$ | Carbon dioxide |
| $CO_2$ **eq.** | Carbon dioxide equivalent |
| $CH_4$ | Methane |
| $O_2$ | Oxygen |
| $N_2$ | Nitrogen |
| $H_2O$ | Water |
| $H_2$ | Hydrogen |
| $NH_3$ | Ammonia |
| **WtE** | Waste to Energy |
| **kWh** | kilo Watt hour |
| **MW** | Mega Watt |
| **MJ** | Mega Joule |
| **PRs.** | Pakistani Rupees |

## Abstract

Unplanned waste disposal in developing countries is the result of increasing population which causes serious environmental threats. Potential of waste to energy production and its impact on reduction of greenhouse gas (GHG) emission may play significant role through economic and environmental returns. This study focuses on assessment of economic and environmental benefits from conversion of waste to energy. The estimated municipal solid waste generation rate is 660 tons/day in Islamabad that can generate millions kilowatt-hour of electricity and will generate millions of rupees as electricity revenue. In this study, anaerobic digestion (AD) technique was considered for estimation of electricity generation from the waste. Production of biogas is 51322 cubic meter per day from organic fraction of waste of Islamabad that is 380 tons per day in 2014. The average electric power generation potential from AD plant is 104973.4 kWh per day that can generate PRs. 289 million annually net benefit from sale of electricity. For economic analysis of the project, net present value (NPV), internal rate of return (IRR), benefit cost ratio (BCR) and payback period (PBP) were estimated which show feasibility of the project. Results show that NPV is PRs. 1113.9 million at 12% discount rate, IRR is 22%, BCR is 3.28 and PBP is 4.8 years. PBP calculated in the study shows that the project will take to pay back its initial cost in almost 4.8 years. Sensitivity analysis was performed to investigate the effect of 10 %, 20 % and 30 % increase in capital cost on feasibility of project. It is estimated that with increase in capital cost by 30% NPV changed to 701.8 million, IRR reduced to 17%, BCR is 2.84 and PBP increases to 6.1 years. Environmental benefit of conversion of municipal solid waste into energy was also estimated. It was found that 206.84 tons $CO_{2eq}$ emission could be reduced or saved by 2030 due to this project. It was found that AD of municipal solid waste of Islamabad is a feasible option for production of renewable energy, waste management and emission reduction.

# Chapter 1

# Introduction

## 1.1 Background

Municipal solid waste (MSW) ordinarily known as refuse or rubbish is generated by residential, commercial and institutional areas and spoils natural environment. Intensification of urbanization globally ensures economic development and industrialization. MSW is spawned with population upturn creating problem for waste management authorities to cope it. Meanwhile, globally greenhouse gases (GHG) emissions from waste increased by 54% from 1990 to 2008, which was in the form of methane gas produced from landfill (Tan et al., 2015). Pakistan's total GHG emissions comprises of 36% methane ($CH_4$) which is highly vulnerable to climate change (UNFCCC, 2011).

With progression of population, waste generation rate per capita is also increasing in Pakistan. Solid waste generation rate in 2014 ranges between 0.283 to 0.612 kg per capita per day and waste generation growth rate is 2.4% per year (EPD, 2014). About 1.44 million population of Islamabad, the capital of Pakistan, generates 660 tons waste per day (CDA, 2014) which is estimated to increase to 1273.5 ton/day in 2050. Waste from households is generally disposed-off by open dumping in the peripheries of the city. In Islamabad, a whole sector I-12[1], worth billions of rupees is used as a dumping site. Using other methods for disposal, instead of dumping, the precious land of the capital can be utilized for housing purpose and the revenue generated from this exercise can be used to make a revolution in solid waste management (SWM) in the whole country.

[1] CDA is trying to explore an effective system of waste collection and still in the process of selecting dump site. https://www.cda.gov.pk

Waste management is not a big concern in recent years. Only small fraction of waste is recycled in Islamabad and remaining part of waste moves to dumpsites which causes air, soil and water pollution and is a big threat for health. The disposal of waste in dumpsites has adverse effect on health for people living near dumpsites (Vrijheid, 2000). Waste management reduces social cost faced by people in response to such health complications. Waste to energy (WtE) techniques are used to minimize both social and economic costs, which include landfilling with landfill gas recovery, anaerobic digestion and incineration. In landfills, methane could be obtained by anaerobic biodegradation of MSW. Sanitary landfill sites help in capturing landfill gas as source of renewable energy. Apart from landfill, anaerobic digestion plants are used for production of biogas from waste, which is a source of renewable energy. For this purpose, organic part of the MSW is to be separated from other components. Waste incineration is also a highly debatable technology and also a sustainable solution for waste management and energy recovery. In this process, waste is burnt at high temperature and heat produced during incineration could be used for electricity generation. In China with modification of imported incinerators, one ton of MSW generates approximately 200 kWh electricity (Cheng and Hu, 2010). But in Pakistan there are no proper incineration plants instead open burning is done in the dumpsites.

Anaerobic digestion (AD) is most promising method of treating organic waste (Lee et al., 2009). AD is a process through which breakdown of biodegradable material take place in the absence of oxygen and end product is biogas. AD utilizes organic waste which reduce GHG emissions and methane recovery from biogas is a cost effective source of renewable energy that could be used as source of fuel and electricity generation. Also AD can eradicate more than 90 percent of disease-causing bacteria that might be a risk to human and animal health (US-EPA, 2014). Biogas produced by AD is one of the most efficient and environmentally beneficial technology used for bioenergy production (Weiland, 2010). Biogas is composed of

50-70% methane ($CH_4$), 25-45% $CO_2$, 2-7% water ($H_2O$), 2-5% nitrogen ($N_2$), 0-2% oxygen ($O_2$), less than 1% hydrogen ($H_2$) and 0-1% ammonia($NH_3$) (Akbulut, 2012). Biogas reduces emissions by thwarting $CH_4$, the main component of biogas, to discharge into atmosphere as $CH_4$ is 21 times stronger than $CO_2$ as greenhouse gas (Braga et al., 2013). Methane which comprises of large portion of biogas can be converted into energy and become a source of economic as well as environmental benefit. In this study dry mesophilic type of AD is used as mesophilic digester operate at temperature from $35^0$ to $40^0$ C which is cost effective technique of AD. Biogas is produced through AD in a complex process, reduces GHG emissions that is beneficial for environment (Arthur et al., 2011). AD is widely used technique for treatment of organic fraction of municipal solid waste and for GHG mitigation (Zeshan et al., 2012).

Energy generated by using these technologies is clean and renewable. Renewable energy from these technologies in our country is of small scale right now but it is a step to save our planet in coming decades from environmental loads. In this scenario if we utilize the renewable resources of this region, that will be much beneficial not only for sustainable power supply but also step towards environmental protection measure and economic strength to save the natural beauty of Islamabad.

Growing energy demand requires energy resources to meet these demands which results in an exponential increase in environmental pollution and global warming (Hafez & Bhattacharya, 2012). Renewable energy has the potential to play an important role to meet energy with sustainability and contributing in environmental and economic return. Renewable energy sources contribute 14% of world energy demand (UNDP, 2000). Renewable energy sources include biomass, geothermal energy, hydropower, solar energy, and wind energy (PRES, 2015). The optimum use of renewable energy technologies could minimize environmental impact (Panwar et al., 2011).

Pakistan is facing severe energy crisis now a days. Keeping in view the supply of electricity to capital city of Islamabad, it is responsibility of a distribution company Islamabad Electric Supply Company (IESCO) which also supplies electric power to district Rawalpindi, Attock, Jhelum and district Chakwal. Electricity demand of IESCO was recorded 1528 MW whereas supply is hardly 1389 MW in 2015-16 creating a gap of almost 139 MW and distribution loss is 9%. The electricity demand of Islamabad is expected to increase more than 3500 MW in 2023 (NTDC, 2012-13). Meanwhile, the current availability of electricity in Pakistan is 17000 MW and demand is 22000 MW creating shortfall of 5000 MW. The average growth of electricity demand is 10% annually and of supply is 7% annually (Rauf et al., 2015). It can be evaluated that a shortfall always remained between demand and supply in both summer and winter season, so there is lots of opportunity for investment in power generation to gain economic benefit.

Energy sectors represent backbone for economic development of a country. Biomass source has great potential to meet energy demands because it contain biogas which is rich in methane and has lower heating value between 15 and 30 MJ/Nm$^3$ that can generate electricity and can be used as vehicle fuel as well (Tippayawong & Thanompongchart, 2010) transporting benefit to individuals and economy as well. Economic optimization is first step for researcher than technology optimization. First priority for researcher is to check the feasibility of project. There are many tools which can help in economic analysis including net present value (NPV), internal rate of return (IRR), payback period (PBP), benefit-cost analysis (BCA) and many more for proving economic viability of a project. This is called techno-economic assessment (TEA) in which technical and economic calculations are combined (Van Dael et al., 2015). Economic aspect of a plant must be considered before taking investment decision. Economic benefit can be calculated by taking into account net benefit of the project. Waste to energy plant will provide revenue from sale of electricity that power maximum areas of Islamabad. It obviously provides financial assistance outweighing the social cost.

This study ponders on economic valuation of dry mesophilic AD plant by using cost-benefit analysis and other parameters and also focus on reduction of GHG emissions from this waste management technique which is a most sustainable option for Pakistan to accomplish its future energy demand.

### 1.2 Objectives of the study

The purpose of this study is to estimate the economic and environmental management benefits of conversion of municipal solid waste into energy. The specific objectives of the study are as follows:

1. To determine the amount of energy production from waste using AD technique and its economic value.
2. To evaluate the economic viability of AD project by using economic parameters.
3. To estimate the environmental benefits of waste to energy conversion using AD technique in Islamabad.

### 1.3 Hypothesis of the study

Keeping in view the above objectives following hypothesis have been made.

**$H_0$**: waste management through AD effect on energy production and GHG reduction.

**$H_1$**: waste management through AD does not effect on energy production and GHG reduction.

In chapter 2, after introduction existing literature is reviewed. Chapter 3 elaborates the data description and methodology techniques. Chapter 4 shows results and discussion part and chapter 5 is of conclusion and policy implications and recommendations.

# Chapter 2

## Literature Review

Waste management is very essential for reduction of health and environmental threats. One of the commonly used practices of waste management is anaerobic digestion (AD). In recovering heat or producing electricity, AD is a successful technology of conversion of organic waste in renewable energy that helps in reducing dependency on fossil fuel. This technology produce biogas which is considered as source of energy production and helps to reduce GHG emissions, beneficial for economy and make climate clean as well. The economic evaluation of anaerobic digestion plants has been estimated by many economists to check the viability of the projects and found that AD is beneficial for economy and environment at same time. Review analysis of some of them is given in this chapter.

Begum et al., (2009) estimated that renewable energy was a source that contribute to meet some what the global energy demand of developed as well as developing countries. Biogas plant could be one of the vital source of renewable energy. The generated gas could be used for cooking, lighting, power generation and the sludge could be used as fertilizer for land. It was one of the alternate sources and offered the developing countries the prospect of increasing their energy supply in a self-reliant way at national and local levels along with the attended economic, social and environmental benefits. Long term sustainable development in all countries, and particularly developing world, requires the gradual shift towards renewable sources of energy that are more equivalently distributed and less environmentally destructive than the fossil fuel sources. The estimation of cost and cash inflow for a biogas plant project was based on analysis. The cost of project includes the capital cost, set up cost and annual operating cost and the inflow considered is selling price of the gas for gas cylinder and the sludge as fertilizer on land from the biogas project. Estimations were made by using two different plant sizes at 100 cubic foot (cft) and at 300 cft. Net present value (NPV) at 10 %, 16% and 18% discount factor, internal rate of return (IRR), Benefit cost ratio (BCR) and Payback period (PBP) was calculated to check the feasibility of project. NPV was 149,091.302 at 10 % discount factor at 100 cft and at 300 cft NPV was found 597,549.62 with 100 % capacity factor which showed viability of project with increase in plant size. Sensitivity analysis was performed by considering an average of 10% increase in price of the raw materials and by determining NPV, IRR, BCR and PBP at 10%, 12% and 15% discount factor. It was found through NPV calculations that project was viable at all three discount factors.

Gebrezgabher et al., (2010) analysed the economic performance of biogas plant using net present value (NPV) and internal rate of return (IRR) as economic parameters. The analysis was based on linear programing model to maximize profit from the sale of energy produced and digestate application. Different scenarios were used in the study for economic assessment that include management and policy scenario in addition to default scenario. The plant produces electricity, heat and three types of technologies that are fixed fraction (FF), ultra-filtration (UF) and reverse osmosis (RO). Electricity yield of 222.30 kWh/ton of feedstock digested produced in default scenario. 6267 NPV and 25% IRR observed highest values under RO that showed greater economic benefit. It was concluded anaerobic digestion (AD) is environment friendly technique and economically attractive for running biogas plant.

Van Dael et al., (2015) estimated the advantages of performing techno-economic assessment (TEA) in early development stage of innovative technology. Techno-economic assessment is used to estimate economic feasibility of technologies. Economic optimization is first step for researchers then comes technology optimization. Net present value (NPV), internal rate of return (IRR) and discounted payback period (DPBP) are some economic assessment tools that can help further research. These tools are excel based that are easy to understand. The advantages of performing TEA was highlighted in the study. With change in economic indicators risk analysis/ sensitivity analysis also explained. The methodology and specific components elaborated in the study that could be used in applying such methods on ultrasonic production of biofuels and chemicals.

Karellas et al., (2009) presented investment decision tool (IDT) of biogas plant project based on agriculture waste. The advantages of anaerobic digestion (AD) and co-digestion elaborated for estimation of biogas production in the study. Three types of feedstock included fresh pig manure, wheat straw (chopped), and glycerol were used to check the project feasibility and for taking investment decision. For this purpose NPV, IRR and different components of project costs were calculated for 10 years and for 20 years separately. NPV for 10 years was 2,312,568 € and for 20 years was 3,812,745 €. Similarly, IRR for 10 years was 13.4 % and for 20 years it was 20.2 %. Discount rate used for such findings was 12%. Payback period had been calculated as 8.76 years for this project. The project was found feasible for further investment and for getting revenues from sale of electricity, thermal energy, and compost and gate fees.

Van Dael et al., (2013) gives the concept of biomass energy conversion park (ECP). Energy Conversion Park is a multi-dimensional biomass conversion site with different technologies where biomass sources are converted into energy. The biomass as main renewable energy source was recognized. The techno economic assessment in the study was performed. Techno-economic assessment (TEA) model consists of cost benefit analysis (CBA) with calculation of net present value (NPV), internal rate of return (IRR), payback period (PBP) and discounted payback period (DPBP). Organic municipal solid waste (OMSW) digestion, co-digestion and multi-dimensional model (integration) based on three models were evaluated. NPV by using ECP was € 3,834,710, IRR was 10%, PBP was 7.55 and DPBP was 11.98 years. Sensitivity analysis was performed to identify the parameters that was most influencing. The investment in multi-dimensional model was found to be economically feasible than in separate two models.

Sengar et al., (2013) checked the economic feasibility of briquetted fuel technology. Briquettes prepared from cashew shell, grass and rice husk after sun drying were used. Further the quality of briquetted fuel related to calorific value, shattering indices test, tumbling test, degree of densification, energy density ratio, resistance to water penetration and water boiling test were checked. For economic analysis net present value (NPV), internal rate of return (IRR), payback period (PBP) and benefit cost ratio (BCR) from all three types of briquettes was calculated. Better results were observed in cashew shell briquettes in fuel calorific value calculation. NPV was found Rs. 2256434.38, PBP was 7.56 months and BCR was 2.93. The combination of grass briquetted fuel found to be economically more feasible than other combinations of briquettes.

Udomsri et al., (2010) examined economic assessment of energy conversion technologies from municipal solid waste (MSW). New approaches were shown in the study that could reduce waste generation and greenhouse gasses emissions. MSW and biogas was found as most important sources of renewable energy and posing low carbon dioxide emissions. The concept of hybrid dual fuel power plants was proposed that include gas turbine cycle and MSW incineration. Net present value (NPV), internal rate of return (IRR) and payback period (PBP) were calculated for economic analysis of plant. In the end the hybrid dual fuel cycle was found more attractive because it had short PBP that was 4.39 years, NPV was found 62.4 M$ and 20% IRR and have more power efficiency. Hybrid technologies and biogas together estimated as doable in reduction of organic waste in future and can reduce CO2 by 4%.

Jaramillo and Matthews (2005) analysed private and social benefits from landfill gas to energy projects with the help of financial and social parameters. For this purpose social and private net present values and internal rate of return (IRR) were calculated. Cost and benefit of project were compared by using different type of equipment that are IC engine, gas turbine, steam turbine and three landfill sites namely, West Lake, west country and modern. Average annual GHG emissions had been calculated that could be reduced by converting landfill gas to energy. It was concluded that the social benefits are 2-6 times higher than the private benefits. Sensitivity analysis was also done in the end to find risk factors in the project.

Savva et al., (2011) analyzed waste to energy plant aspects such as public opinion, marketing, promotional activities, environmental depollution, financing options and operational costs in Kotsiatis landfill in Cyprus. The environmental, technical, economical and marketing aspects and techno economical concepts of the study were based on personal interviews. Net present value (NPV), internal rate of return (IRR) and cash flow were calculated for economic evaluation of the study. The best practice to be implemented was considered thermal incineration treatment to produce thermal energy which then converted into electrical energy with use of stream turbine. A small WtE plant of 150,000 tons/ year showed economically feasible even without government support. These plants improved the quality of life, reduced environmental problems and shown economically viable. WtE plant with capacity of incinerating 100,000 tons waste /year results 11 MW of reliable power was also found. NPV was €2,655,730, IRR was 10.5% and positive cash flow was found to pay back after 9 years of operation.

Bozorgirad et al., (2013) analysed and compared the environmental and economic performance of incineration and ethanol production in three scenarios of waste management strategies. Scenario 1 used was heat recovery from incineration, scenario 2 was electricity generation from incineration and scenario 3 was ethanol production. ISO 14040 life cycles assessment framework was used to conduct environmental impact assessment of three scenarios and economic impact of each scenario was assessed by benefit-to-cost ratio and net present value (NPV) analysis. Environmental life cycle assessment model indicated that scenario 3 had highest benefit for human health and ecosystem diversity. Scenario 1 had worst impacts while scenario 2 determined the best option to avoid resource depletion. Under scenario 3 BCR was 1.81 and NPV was $93\times10^6$ USD that showed highest values and found feasible from economic point of view.

Ali et al., (2012) analysed that conversion of green waste of Thailand into renewable energy was not only an environmental friendly technique but also financially rewarding process. Further $CO_2$ emissions and energy consumption of Thailand was estimated increasing day by day. 85% waste of Talaad Thai (green market in Thailand) composed of organic waste and suitable for biogas production could also reduce environment burden. Benefit cost analysis (BCA) was done for estimation of profit obtained from conversion of waste into biogas by comparing economic benefit with economic cost. The BCA conducted was based on existing and proposed scenarios. The BCA was 3.37 and return period of total investment was found 2 years. In existing scenario the installation of biogas plant was found cost beneficial that become reduced with production of biogas by use of anaerobic production (AD) technology in proposed scenario.

Akbulut (2012) analysed the importance of biogas production by anaerobic digestion (AD) from organic feedstock. Manure was estimated as a major source of environmental pollution that could be reduced by conversion of manure into renewable energy via AD as AD had potential to manage organic waste into cost effective and environmental friendly manner. The technical and economic performance of AD of farm-scale biogas plant was estimated in the paper. The estimations had been carried out on the basis of net present value (NPV) and energetic payback period (EPBP). Dairy cow manure and sheep dung were used for NPV analysis as substrate. NPV estimated value was 9.8, EPBP was 3.7 years and GHG emissions had reduced by 7506 t $CO_2$ per year. Further, electricity energy and heat energy were estimated 277.99 kWh and 320.76 kWh per day.

Forgács et al., (2013) estimated that slaughterhouse waste had high methane potential and suitable for anaerobic digestion (AD) and created great concern. A simple process of utilization of feather waste by AD was used to produce renewable energy. Calcium hydroxide with chemical formula $Ca(OH)_2$ was applied to increase the digestibility of keratin (feather is composed of 90-95% of keratin protein) which improve the biogas yield. The methane production pre-treated and untreated of feather was also compared. It showed that pre-treated samples produced two time more methane than untreated samples. Two possible utilization of biogas were investigated as heat and electricity production and as vehicle fuel. Utilization of biogas as fuel was found to be economically more feasible as it had high internal rate of return (IRR) between 10.7 and 23.7% under different scenarios. Sensitivity analysis also done with change in gate fee and cost of feather.

Chanekarn et al., (2015) analysed the economics of 3 MW electricity generation power plant that was fuelled by biogas from three sources including decantation cake, wastewater and elephant grass from palm oil industry in Thailand.  The biogas plants were hybrid channel disaster (HCD) of wastewater and completely stirred tank reactor (CSTR) co-digestion of decanter cake and elephant grass with wastewater. The analysis was based upon cost and revenue of power plants. The estimations were made on non-subsidy and 20 % subsidy supporting scheme. Net present value (NPV), internal rate of return (IRR) and payback period (PBP) values were used to know about the final survival of projects. Without subsidy with life span of 20 years of project, IRR was 29.9 % with PBP more than 13.62 years was calculated whereas with 20 % subsidy, IRR was 20.19 with PBP more than 10.9 years considering HCD and CSTR system was estimated that showed financial strength of plants.

Chen et al., (2015) found that China will be the biggest contributor of CO2 emissions around 2030. China also expanding its livestock production facilities which could be utilized in methane production and greenhouse gases reduction from conversion into electricity. Three different sizes of hog farm were selected and also estimated cost benefit analysis of three digester systems. The anaerobic digesters in all three farms were continuously stirred tank reactors (CSTR). The study was based on revenue from electricity generation, carbon offset and saving sewerage charges. Carbon emission reduction rate was observed above 55 % and if traded carbon emission reduction in carbon offset market at high price then it would be estimated profitable and positive net present values (NPV) of all three farms with government subsidy for methane digester system.

Braga et al., (2013) analysed that fuel cells could convert hydrogen and oxygen chemical energy into electrical energy efficiently and could reduce emissions in environment. Steam reforming process was used for hydrogen production. The economic feasibility of the process was evaluated by the analysis of payback period (PBP) and cost of biogas steam reformer and hydrogen production. The emissions during natural gas and biogas reforming process was also compared and found that biogas reforming is environmental friendly. Ecological efficiency was used for calculation of pollutants of the study and estimated 94.95% pollutants. The hydrogen production cost was 0.27 US$/kWh and estimated PBP was 8 years which concluded that the technology used was economically and technically feasible and had lower environmental impact.

Li et al., (2015) analysed the by-product of wine or distillers dried grains with soluble (DDGS) could be a good feed stock for pigs in China. It was analysed that annual 3 million tons of wine can produce 9 million tons of DDGS. It was studied that pig manure is a big source of bioenergy derived from anaerobic digestion (AD) of manure. It was also studied that mass flow and energy was balance for biogas plant. The study focused on economic analysis and mass flow and energy balance for biogas plant by using two continuous using stirred tank reactors at different temperature. For economic analysis cost benefit analysis process was used with calculations of net present value (NPV), internal rate of return (IRR) and payback period (PBP). It was estimated that project is feasible at 0.01 NPV and 6% IRR. The PBP was calculated as 10.9 years with $50,811 annual benefit. The purpose of biogas plant in the study was waste treatment, renewable energy production and nutrient rich fertilizer.

Rajendran et al., (2014) found that biogas produced from organic fraction of municipal solid waste (OFMSW) was not only suitable for energy production but also economically sound. The study was focused on biogas production from OFMSW using Aspen Plus in six different scenarios. Techno-economic model was used to identify the feasibility of project at industrial level located in Boras, Sweden. Aspen process economic analyser was used for economic analysis and also net present value (NPV) and sensitivity analysis of project was carried out. The investment in treatment of MSW for biogas production was observed positive and having positive NPV in most scenarios of the study. After 20 years of operation, NPV was found 34.6 USD. The use of biogas for vehicles was estimated economically and environmentally feasible as it reduced many problems.

Leme et al., (2014) analysed techno-economic and environmental aspects of municipal solid waste (MSW) in Brazil and also compared alternatives to energy recovery from MSW under four scenarios. From sale of electricity and carbon credits the benefits were estimated and life cycle assessment (LCA) methodology was applied for environmental estimations. Two different alternatives for energy recovery including landfill biogas and waste to energy (WtE) facility was used by using incineration of MSW to generate electricity. Negative net present value (NPV) of WtE project was observed that shown the project was not economically viable. The scenario of 500,000 inhabitants at landfill scenarios showed better results with positive NPV and 15.6 % internal rate of return (IRR) than 100,000 inhabitants showed that largest population scenario had worst performance. Sensitivity analysis was also done in the study on the basis of price of electricity and shown influence on return of project.

Oliveira and Rosa (2003) analyzed that energy could be produced from municipal solid waste that is equivalent to 17% of total power consumption in Brazil. It was highly beneficial in social, economic and environmental perspectives as it could open thousands of jobs and reduce GHG emissions. Cost benefit index (CBI) was used for economic analysis. It was proved from the study that energy conservation through recycling was quite feasible. The power conservation to projects implemented by Federal Government was also compared. Net operating revenue of the scheme was observed US$ 4 billion/year. It was analyzed that garbage management would avoid environmental cost and best alternative for energy use. It was suggested that expanding Brazil's power sector relevant to thermo-power plant could reduce GHG emissions in Brazil.

Ryu (2010) found that waste to energy was suitable method of waste management and renewable energy production. The potential for energy production and reduction of GHG emissions from MSW in South Korea was estimated in this study. The energy from waste was calculated for GHG reduction by direct release of anthropogenic carbon, $N_2O$, $CH_4$ and reduction in GHG emissions by fossil fuel displacement. Landfilling $CH_4$ emissions from biogenic carbon in waste was also estimated. It was found from results that GHG emissions has been doubled to 599.5 MtCO2, eq. /yr. over 16 years. It was concluded from the study that current level of GHG emissions in Korea is significant but could be reduced by increased conversion of waste into energy with combined heat and power.

Uusitalo et al., (2014) found that biogas could be used as energy source for transportation and electricity and heat production. Biogas production from bio waste, waste water treatment plant sludge and agricultural biomass was studied in this paper. The use of both biofuel and fossil fuel in transportation was compared with each other and also compared the transportation use with electricity and heat production and composing of heat stock. The research was conducted by using life cycle assessment method and calculations followed the directive 2009/28/EC, ISO 14040 standard and greenhouse gas protocol. It was realized that the use of biofuel has high potential in reduction of GHG emissions faster than from fossil transportation fuel. It was found that GHG reduction varied from 49% to 84% from use of biofuel.

Arthur et al., (2011) represented that wood fuel and dung was used as fuel source in Ghana which was harmful in environmental, social and health perspective. The use of fossil fuel and biomass has enhanced the interest of alternative cleaner source of energy. Biogas was found as a useful replacement of wood fuel and dung in Ghana. Biogas produced through anaerobic digestion in a complex process, reduced GHG emissions and beneficial for environment of Ghana. With proper management of biomass, AD was also helpful in income generation, lifestyle improvement, cost saving, environmental sustainability, increase in agricultural productivity and women empowerment in Ghana. It was found in this study that Ghana has potential of constructing 278,000 biogas plants. The study represents energy situation, and utilization of biogas technology, its benefits and its challenges in Ghana.

Masse et al., (2011) described the method of on farm biogas production to reduce GHG emissions and other environmental impacts related to more sustainable livestock operations. Livestock contribute 18% GHG emissions and also degrade land and water. The study showed that GHG emissions could be reduced due to reduction in use of chemical fertilizers, reduction from stored and land applied manure and from the production of renewable energy. The potential of AD technologies was reviewed and assessed the environmental, social and agricultural benefits of AD technologies in this study. It is estimated that anaerobic digesters produce renewable energy as biogas with $CH_4$ usual content of 60-80% and has potential to eliminate uncontrolled $CH_4$ emissions from land manure and also reduced $N_2O$ emissions by 50% as compared to raw liquid swine manure and more than 24% as compared to mineral fertilizer. It was found that psychrophilic AD reduced $NH_3$ emissions by 25% compared with raw liquid swine manure. The load of organic pollutants reduced by AD in livestock manure and protected the water quality. In addition, AD reduced odour emissions by 70-98% in rural region. Thus, it was concluded that adaptation of AD was a practical way to reduce C and environmental footprints of food and livestock origin.

Johari et al., (2012) argued that human activities contributed in GHG emissions in environment and responsible for environment degradation. Mitigation of emissions and management of MSW was considered as major challenges in growing economies. It was analyzed that landfill gas essentially methane ($CH_4$) and carbon dioxide ($CO_2$) from MSW could be converted into green energy by biodegradation process. The methane estimation calculations from landfill and its environment and economic benefits in Malaysia was the major objectives of the study. The IPCC methodology was used to estimate methane emissions. It was concluded that anthropogenic methane emission is about 310,220 tons per year based on 196,000 tons MSW in peninsular Malaysia in 2010. It was further estimated to generate 1.9 billion kWh of electricity per year worth over RM 570 million which leads to $CO_2$ reduction of 6,514,620 tons per year which was highly beneficial for environment as well as for economy of Malaysia.

It is concluded from all above literature that waste management problem of the world are strongly related to growing population. Effective waste management is of utmost importance to a country. In recent years many countries have demonstrated AD technology for waste management and to evaluate its environmental and economic benefit for their economy. The same economic and environmental parameters could be used as discussed in this study.

## Chapter 3

## Data Description and Methodology

### 3.1 Introduction

In this chapter, methods used for the present study have been discussed. The methodological techniques and ways for data collection are very important for empirical study. A certain way of data collection, as well as certain tools and techniques have been applied for data analysis in order to achieve the desired objectives of the study for the selected study area. The energy production from municipal solid waste has been calculated considering the dry mesophilic anaerobic digestion (AD) method. Similarly, GHG emission reduction from the solid waste of selected study area has been calculated by using IPCC good practice guideline method. The excel sheet was used for different analysis of data.

### 3.2 Study Area and MSW generation

The present study was conducted to manage MSW of the capital city of Pakistan. Islamabad was thus considered as study area in this study, which is a green and well planned city of the country but in the last few years its population and MSW generation have grown dramatically. Rapidly increasing population and residential areas have created number of social and economic problems including electricity shortage and environmental degradation. The amount of waste generation in Islamabad is 660 tons per day having 64 % household waste (CDA, 2014). Organic fraction of Municipal Solid Waste (OFMSW) is used as 57.6% of total waste which is used in production of biogas and hence electricity.

### 3.3 Data Sources

Data used in this study have been taken from different sources. These include Alternative energy development board (AEDB), Pakistan council of renewable energy technology (PCRET), Capital development Authority (CDA), the leading independent energy suppliers

(SSJD Group), National transmission dispatch company (NTDC), National electric power regulatory authority (NEPRA), Islamabad electricity supply company (IESCO), Planning commission (PC), Intergovernmental Panel on Climate Change (IPCC), Independent power producers (IPPs). Direct interviews from representatives or officials of AEDB, PCRET and CDA were conducted for this purpose.

### 3.4 Electricity Tariff

The determination of tariff for power producers is responsibility of NEPRA. NEPRA determines electricity tariff by taking into account Debit: Equity ratio, IRR and some technical and financial parameters (NEPRA, 2013-14). If IPPs want to settle the tariff after negotiation, the NEPRA will determine tariff after consultation with power producers. The tariff used in this study is PRs. 11.2239/ kWh that is the tariff which was determined by NEPRA for the leading independent energy suppliers (SSJD Group). SSJD bioenergy limited is a registered company in USA. This group is a leading developer of renewable energy suppliers in Pakistan. They are developing a biomass power project in Mirpurkhas, Sindh with installed capacity 12 MW.

### 3.5 Conversion Factors

The factors by which waste is converted into biogas and biogas is converted into electricity is a key factor of the study. It has been found that one ton of organic fraction of municipal solid waste when collected separately can produce biogas up to 200 $m^3$ (Bolzonella et al., 2006). In this study calculations are based on 135$m^3$ biogas production from one ton of OFMSW. It is also found that one $m^3$ biogas is equal to 2.5 kWh electricity (Uddin, 2016).

### 3.6 Plant size

Plant size has been calculated by multiplying amount of waste with retention time. The retention time used in this study is 25 days. Total solid (TS) present in original mixture of waste is usually 30 % while remaining 70 % is moisture content of waste (kigozi et al., 2014). To minimize the TS of waste from 30 % to 15 % (as dry digestion process at 15 % TS has been considered in this study), water has to be added in it. The 80% of total digester size is kept as working volume which is filled with prepared waste and the remaining 20 % size is left empty. Total size of digester is calculated as 23760 $m^3$.

### 3.7 Cost estimations of project

#### 3.7.1 Capital cost

Capital costs are onetime expenses that is necessary for investment. It is fix cost on which all economic parameters are relying which measure the hazard that would inherit in a project. Its components used in this study include the following.

##### 3.7.1.1 General Site Works

It includes 15-acre land used for project, 3.5 acers for digestion plant, 10 acers for Waste Processing and 1.5 acers for Roads, Buildings etc. Total land is worth of PRs. 57.6 million. It also include clearing, dewatering, geotechnical investigations, Roadworks, paving, roadway lighting, signage, fencing/gates, storm water management, utility connections, buried piping (sewer, gas, water) etc.

##### 3.7.1.2 New Buildings

New building costs include Tip floor (2000 $m^2$ x PRs.24, 000/$m^2$), pre-processing, dewatering building (1000 $m^2$ x PRs. 30,000 /$m^2$), wet processing building (2000 $m^2$ x PRs. 30,000/$m^2$), admin areas, electrical/mechanical, maintenance, laboratory, scale house and 2 scales, miscellaneous structures (at tanks) etc. included in such costs.

#### 3.7.1.3 Major Tankage

Tanks cost is estimated by multiplying digester size with PRs.7000, because cost of one cubic meter size of digester is PRs. 7000 (PCRET, 2016). Cost for major tanks include digesters, gas storage tank, liquid (feedstock) storage tank, process water storage tank etc.

#### 3.7.1.4 Pre-Processing Equipment

It includes cost of trommel screen that is used to sort dry food waste of different sizes and to get rid of dust particles. It is used to recuperate valuable reserves. It also includes cost of comminuting drums.

#### 3.7.1.5 Main and Post-Processing Equipment

It includes cost of feed pumps, mixing units, conveyors, screw presses, centrifuge, vibrating screen, other process piping, valves, pumps, small tankage etc.

#### 3.7.1.6 Flaring and Odour Control

It embrace Flare and gas trane, bio filter (concrete walls, media support, and media), blower, ducting, humidity control, other controls, etc.

#### 3.7.1.7 Electrical and Steam Generation

Cost of steam generation package (for digester preheating) and electrical generation package-engine generator set ($2,200/kW x 5321.57kW) etc.

#### 3.7.1.8 Miscellaneous

Residue compactor, bins, containers, platforms, catwalks, ladders, metal works, wastewater treatment package allowance etc.

#### 3.7.1.9 Others

Others capital cost include registration fee with AEDB, registration fee with Private Power and Infrastructure Board (PPIB), processing fees for issuance of letter of support to PPIB and licence fee submitted to NEPRA.

### 3.7.2 Operational & Maintenance cost

These are expenses that are needed for building a project. It is day to day activity because a facility cannot plan without being maintained.

#### 3.7.2.1 Staff requirement

Staff required for AD project include plant manager, process control operators, tip floor operators, maintenance technicians, scale house operators, reception, marketing manager, general labourers and lab technician. Their salaries are include in cost of plant.

#### 3.7.2.2 Fuel Cost

It is assumed that 10 litre fuel are used for rolling equipment per hour. There are two vehicles running and no. of working hours in a day are 16. Working days in a year are assumed 300 days. Market price of fuel used is 75.3 PRs. per litre.

#### 3.7.2.3 Maintenance

Maintenance cost include expenses of maintaining the equipment, building and site work, tankage and odour control that is assumed 4%, 0.5% and 1% of capital cost.

#### 3.7.2.4 Others

Rolling Equipment Leases and maintenance, wastewater treatment, lab analysis costs, administration, legal, accounting costs, service contracts, Product haul and tip Fees at curing site, residue disposal, greenhouse gas credits etc. are all included in these expenses.

### 3.8 Economic Analysis

Feasibility of a project depend upon wise decision. Feasibility determines the right way of project that tells us it should be undertaken in future. Its main objective is to provide decision-making tool for project. Economic analysis is based on cost of a project. For completion of this section analysis is done on excel spread sheet. The economic life of plant is assumed as 20 years. This section of study is based in Benefit-Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP) and sensitivity analysis has done to find the sensitivity of project.

#### 3.8.1 Discount rate

Discount rate is interest rate charged by Regional Reserve Banks to commercial banks. It is the rate at which future benefits are debased as compared to present value. High discount rate means financial amount is expected in future is less valuable than today (Rosenheck et al., 2000). It is used to determine present value of future cash flow and is said to be discounted cash flow analysis. The value we give to a project at different time period is resolute by discount rate. Discount rate should not be so high depending upon interest rate and cost of project. World Bank use 12 % discount rate for its economic and evaluation projects (Khatak, 2012). So discount rate used in this study is 12% as well because it is not too high nor too low. It gives us feasible results.

#### 3.8.2 Net present value (NPV)

NPV is arithmetic sum of present value of proceeds and present value of spending (Bierman Jr & Smidt, 2012). It shows difference between discounted benefit and discounted cost. It could be calculate by summing total cost and total benefit and multiplying by discount factor. It is used to check the feasibility of a project. If NPV is greater than zero then the project is feasible.

NPV = $\sum_{t=1}^{n}(Bt - Ct) /(1+i)^{t}$

### 3.8.3 Internal rate of return (IRR)

IRR is discount rate at which NPV become equal to zero. IRR should be greater than interest rate, higher IRR greater will be the feasibility of project. It shows point at which total benefit become equal to total cost. If IRR is greater than interest rate the project will be beneficial (Kierulff, 2008).

IRR= Lower Discount Rate ($d_1$) + [($d_2$-$d_1$) × $NPV_1/NPV_1-NPV_2$]

Where

$d_1$ is lower discount rate

$d_2$ is higher discount rate

$NPV_1$ is NPV value at lower discount rate

$NPV_2$ is NPV value at higher discount rate

### 3.8.4 Benefit Cost Ratio (BCR)

BCR is ratio of sum of discounted benefit and sum of discounted cost. It shows ratio of present value of cost and benefit (Bierman Jr & Smidt, 2012). BCR tells us the overall value of project. Higher the BCR the better is to invest in project. It scrutinizes potential action that improve communal prosperity (Ali et al., 2012).

BCR= $\sum_{t=1} n \quad (B_t/1+r) \quad / \quad \sum_{t=1} n \, (C_t/1+r)$

### 3.8.5 Payback period (PBP)

The time that is needed to recuperate the original investment. It represents the number of years that is needed for a project to pay for itself (Begum et al., 2009).

Pay Back Period= Cost of Project / Annual cash inflows

### 3.8.6 Sensitivity analysis

Sensitivity analysis is carried out to determine NPV, IRR, BCR and PBP by changing different variables such as discount factor, initial cost. It shows sensitivity of a project. In this study there is change in capital cost of project with 10 %, 20% and 30% increase and with decrease in waste amount by 5% to check the capacity of plant.

## 3.9 Environmental benefits

Anaerobic digestion can reduce emissions from conversion of MSW into energy. Pakistan is contributing 0.8% of global GHG emissions which include 54% $CO_2$, 36% methane and 9% $N_2O$ emissions (PC, 2010). . Anaerobic digesters produce renewable energy as biogas with $CH_4$ usual content of 60-80% (Masse et al., 2011). Waste management is an inimitable sector which can limit from becoming major source of pollutant. Methane emissions from landfill are deliberated to be the major source of climate impact and would no longer be the source of emission (UNEP, 2010). Emissions from MSW of Islamabad were calculated using IPCC methods to estimate the emission reduction after its conversion into energy.

### 3.9.1 Methane emission from landfill

The method is based on following equation

$$CH_4 \text{ emissions (Gg/yr)} = [(MSW_T \cdot MSW_F \cdot L_0) - R] \cdot (1 - OX)$$

Where:

$MSW_T$ = Total MSW generated (Gg/yr)

$MSW_F$ = Fraction of MSW disposed at SWDS

$L_0$ = Methane generation potential [MCF • DOC • $DOC_F$ • F • 16 / 12 (Gg $CH_4$/Gg waste)]

MCF = Methane correction factor is used as value 1 for managed disposal site (values shown in table 1)

DOC = Degradable organic carbon [fraction (Gg C/Gg MSW)]

$DOC_F$ = Fraction DOC dissimilated. The IPCC Guidelines provide a default value of 0.77 for $DOC_F$

F = Fraction by volume of $CH_4$ in landfill gas and its value is 0.5 given by IPCC

R = Recovered $CH_4$ (Gg/yr). The default value for methane recovery is zero

OX = Oxidation factor is share of methane oxidation in upper layer of soil. The default oxidation factor in the IPCC Guidelines is zero.

**Table 3.1: Classification and methane correction factors**

| Type of Site | Methane Correction Factor (MCF) Default Values |
|---|---|
| Managed | 1.0 |
| Unmanaged – deep ( >5 m waste) | 0.8 |
| Unmanaged – shallow (<5 m waste) | 0.4 |
| Uncategorized SWDS | 0.6 |
| Managed SWDS must have controlled placement of waste (i.e. waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include some of the following: cover material, mechanical compacting or leveling of waste. The default value of 0.6 for uncategorized SWDS may be inappropriate for developing countries with a high percentage of unmanaged shallow sites, as it will probably lead to overestimation of emissions. Therefore, inventory agencies in developing countries are encouraged to use 0.4 as their MCF, unless they have documented data that indicates managed landfill practices in their country. Source: Reference Manual of the IPCC Guidelines. | |

[2]Source: IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2001)

In IPCC report, the DOC value for Pakistan in 1999 data is 0.16 through this equation.

$$DOC = (0.4 \cdot A) + (0.17 \cdot B) + (0.15 \cdot C) + (0.3 \cdot D)$$

Where A= waste occupied by paper and cloth

[2]http://www.ipcc-nggip.iges.or.jp/public/gp/english/5_Waste.pdf

B= garden and nonfood waste

C= food refuse

D= Fraction of waste that is wood or straw

Global warming potential GWP for $CO_2$ is assigned value 1 and for $CH_4$ is 28 (IPCC, 2014).

**Table 3.2: Global Warming Potential for Given Time Horizon**

| | Lifetime (yr.) | GWP | | GTP | |
|---|---|---|---|---|---|
| | | **Cumulative forcing over 20 years** | **Cumulative forcing over 100 years** | **Temperature change after 20 years** | **Temperature change after 100 years** |
| **$CO_2$** | | 1 | 1 | 1 | 1 |
| **$CH_4$** | 12.4 | 84 | 28 | 67 | 4 |
| **$N_2O$** | 121 | 264 | 265 | 277 | 234 |
| **$CF_4$** | 50,000.0 | 4880 | 6630 | 5270 | 8040 |
| **HFC-152** | 1.5 | 506 | 138 | 174 | 19 |

Source: Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, 2014

# Chapter 4

# Results and Discussion

## 4.1 Introduction

This chapter comprises of economic and environmental analysis of anaerobic digestion plant. It consists of five main sections. The first part consists of biogas production from waste, second part encompasses electricity generation from biogas, third part embraces economic analysis including cost benefit analysis, net present value, payback period, internal rate of return calculations based on capital cost and operational and maintenance (O&M) cost. Fourth part is of emission reduction calculation that could be abridged its contribution in GHG emissions named environmental analysis. The last part is of discussion.

## 4.2 Waste generation and Biogas production

Biogas is result of anaerobic digestion (AD) of biodegradable material of waste that is organic fraction of municipal solid waste (OFMSW) used in this study. Pakistan council of renewable energy technology (PCRET), Pakistan council for appropriate technologies (PCAT) and Pakistan renewable energy society (PRES) all are working on research and development of biogas production. Currently 5357 biogas plants have been installed in different areas of Pakistan (Uddin, 2016). In Islamabad 30 biogas plants have been installed from 2007 to 2012 and 2513 in all over Pakistan (PCRET, 2016). Biogas is renewable energy resource that can not only solve energy crisis problem but also help in reduction of unemployment in the country and have positive impact on environment.

In Islamabad per capita waste generation rate is 0.283-0.613 kg/day (CDA, 2006). Based on previous and present data of waste production and according to increase in population of Islamabad amount of waste was estimated and forecasted for next years. Out of total waste 55-60% is organic fraction of municipal solid waste (OFMSW) (CDA, 2014). It is estimated that one ton of OFMSW produced 135m$^3$ biogas as one ton of OFMSW can produce biogas upto 200m$^3$ (Bonzonella et al., 2006). Amount of waste and biogas production is given in table 4.1. It can be seen in the table that waste generation is increasing day by day and will reach up to 970 ton per day by 2030. If this waste is utilized in biogas production then such surge could be abated.

**Table 4.1: MSW and biogas production rate**

| Years | Waste (tons/day) | OFMSW (ton/day) | Biogas Potential (m$^3$/day) |
|---|---|---|---|
| **2010** | 574 | 331 | 44645 |
| **2011** | 592 | 341 | 46002 |
| **2012** | 609 | 351 | 47394 |
| **2013** | 627 | 361 | 48751 |
| **2014** | 660 | 380 | 51322 |
| **2015** | 668 | 385 | 51944 |
| **2016** | 691 | 398 | 53724 |
| **2017** | 711 | 410 | 55339 |
| **2018** | 732 | 422 | 56938 |
| **2019** | 752 | 433 | 58480 |
| **2020** | 770 | 443 | 59863 |
| **2021** | 792 | 456 | 61594 |
| **2022** | 812 | 467 | 63103 |
| **2023** | 831 | 479 | 64637 |
| **2024** | 851 | 590 | 66179 |
| **2025** | 871 | 502 | 67742 |
| **2026** | 891 | 513 | 69321 |
| **2027** | 911 | 525 | 70838 |
| **2028** | 931 | 536 | 72399 |
| **2029** | 951 | 548 | 73956 |
| **2030** | 971 | 559 | 75510 |

### 4.3 Energy generation from biogas

Biogas can generate 20 MJ energy due to its high calorific value from one cubic meter that is 6 kWh calorific value per cubic meter (Makai & Molinas, 2013). This energy is in the form of electricity. However, due to efficiency of the generator, one cubic meter of biogas generates 2.5kWh electricity only. Calorific values and electricity generation rate per day from biogas is given in table 4.2. Biogas production is function of organic content. With more fraction of organic content in MSW the biogas potential will move up in coming decades. In 2030 it is expected to generate 75510 cubic meter biogas from OFMSW per day leading to more benefit and about 132142.70 kWh electricity per day could be sold out of total electricity produced (i.e. 188775 kWh/day), as 30% of total electricity is used to operate the plant. Table 4.2 shows the production and utilization of electricity for benefit analysis from 2010 to 2030. The average electricity production from AD plant has been 104973.4 kWh per day.

### 4.4 Economic Analysis of AD plant

Economic analysis is based on initial capital cost and operational and maintenance cost. Before taking investment decision economic feasibility of any project is an important factor. In this section the benefit related to sale of electricity and cost of AD plant are discussed. The investment or initial cost is taken as PRs. 1373.46 million (Appendix A). Table 4.3 shows the total cost and benefit of plant. For analysis of profitability of plant, net present value (NPV) and internal rate of return (IRR) has been premeditated. The capital cost is taken as fixed cost and variable cost include O & M cost which are PRs. 63.7318 million annually. The life span of plant is taken as 20 years. Expected benefit is on the basis of tariff and net benefit is in the form of profit that increases after deduction of total cost of project. The discount rate assumed is 12%.

**Table 4.2: Electricity generation rate from biogas**

| Years | Biogas Potential ($m^3$/day) | Calorific value (kWh/day) | Total Electricity (kWh/day) | Electricity available for sale (kWh/day) |
|---|---|---|---|---|
| **2010** | 44645 | 267872 | 111613 | 78129.31 |
| **2011** | 46002 | 276015 | 115006 | 80504.25 |
| **2012** | 47394 | 284366 | 118486 | 82940.08 |
| **2013** | 48751 | 292509 | 121879 | 85315.02 |
| **2014** | 51322 | 307930 | 128304 | 89812.80 |
| **2015** | 51944 | 311662 | 129859 | 90901.44 |
| **2016** | 53724 | 322343 | 134309 | 94016.61 |
| **2017** | 55339 | 332032 | 138347 | 96842.73 |
| **2018** | 56938 | 341630 | 142346 | 99642.11 |
| **2019** | 58480 | 350877 | 146199 | 102339.16 |
| **2020** | 59863 | 359179 | 149658 | 104760.47 |
| **2021** | 61594 | 369566 | 153986 | 107789.97 |
| **2022** | 63103 | 378617 | 157757 | 110430.22 |
| **2023** | 64637 | 387821 | 161592 | 113114.34 |
| **2024** | 66179 | 397071 | 165446 | 115812.43 |
| **2025** | 67742 | 406450 | 169354 | 118547.92 |
| **2026** | 69321 | 415925 | 173302 | 121311.43 |
| **2027** | 70838 | 425029 | 177096 | 123966.90 |
| **2028** | 72399 | 434394 | 180997 | 126698.23 |
| **2029** | 73956 | 443737 | 184890 | 129423.18 |
| **2030** | 75510 | 453061 | 188775 | 132142.70 |

Results show that Internal Rate of Return (IRR) is 22% that is more than discount rate and is desirable for project to undertake. NPV is PRs. 1113.9 million which is positive value and suitable for project. There exists a close relationship between NPV and IRR. The relationship is given in Fig 4.1. The IRR is discount rate at which net present value becomes zero. It could be seen in Fig 4.1 that at 22 % discount rate, NPV is zero. With further increase in discount rate net present value becomes negative which is not acceptable for project. The IRR value shows the edge point at which project is feasible and not acceptable. So, discount rate could not be increased further. Payback period (PBP) is used to calculate the time in years that is required to pay back initial cost of AD plant according to balance or cumulative cash flow of plant. The cumulative cash flow is given in Table 4.3 and shown in Fig 4.2 with some negative values in starting years and start earning return after fourth year shown by positive value in fifth year of AD plant. The PBP calculated is 4.8 years meaning that plant will take four years and ten months to payback initial cost and start earning yield. The values of all economic parameters shows that project is feasible and praiseworthy to be under taken.

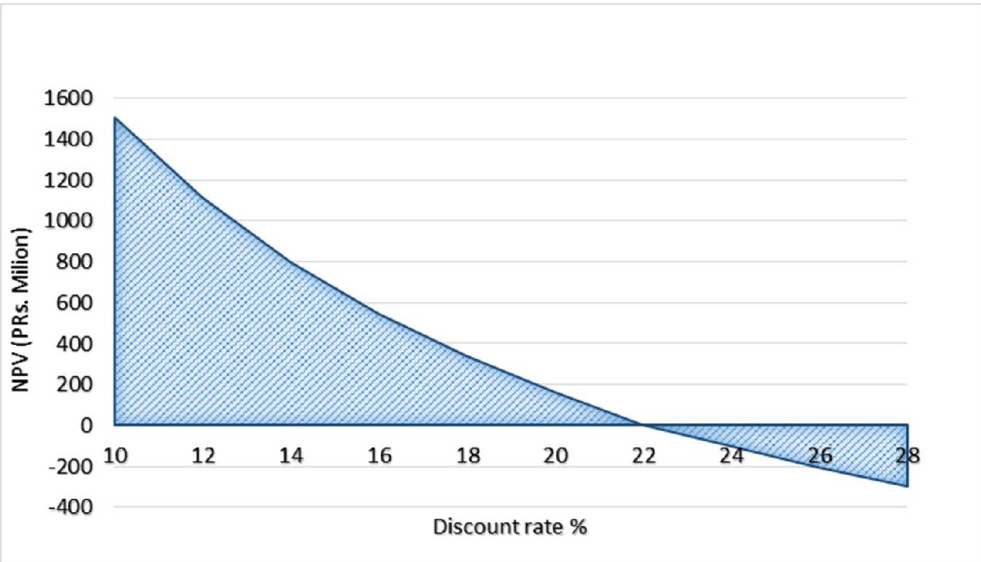


**Fig 4.1: NPV and Discount rate relationship**

**Table 4.3: Economic analysis of AD plant**

**(PRs. Million)**

| | Years | Initial Capital cost | O&M cost | Total Cost | Benefit | Net Benefit | Cumulative Cash Flow |
|---|---|---|---|---|---|---|---|
| **0** | 2010 | 1373.46 | 0 | 1373.46 | 0 | -1373.46 | -1373.46 |
| **1** | 2011 | 0 | 63.7318 | 63.7318 | 329.804 | 266.072 | -1107.39 |
| **2** | 2012 | 0 | 63.7318 | 63.7318 | 339.783 | 276.051 | -831.337 |
| **3** | 2013 | 0 | 63.7318 | 63.7318 | 349.512 | 285.780 | -545.557 |
| **4** | 2014 | 0 | 63.7318 | 63.7318 | 367.938 | 304.206 | -241.351 |
| **5** | 2015 | 0 | 63.7318 | 63.7318 | 372.398 | 308.666 | 67.31552 |
| **6** | 2016 | 0 | 63.7318 | 63.7318 | 385.160 | 321.428 | 388.7438 |
| **7** | 2017 | 0 | 63.7318 | 63.7318 | 396.738 | 333.006 | 721.7498 |
| **8** | 2018 | 0 | 63.7318 | 63.7318 | 408.206 | 344.474 | 1066.224 |
| **9** | 2019 | 0 | 63.7318 | 63.7318 | 419.255 | 355.523 | 1421.748 |
| **10** | 2020 | 0 | 63.7318 | 63.7318 | 429.175 | 365.443 | 1787.191 |
| **11** | 2021 | 0 | 63.7318 | 63.7318 | 441.586 | 377.854 | 2165.044 |
| **12** | 2022 | 0 | 63.7318 | 63.7318 | 452.402 | 388.670 | 2553.715 |
| **13** | 2023 | 0 | 63.7318 | 63.7318 | 463.398 | 399.666 | 2953.381 |
| **14** | 2024 | 0 | 63.7318 | 63.7318 | 474.452 | 410.720 | 3364.101 |
| **15** | 2025 | 0 | 63.7318 | 63.7318 | 485.658 | 421.926 | 3786.027 |
| **16** | 2026 | 0 | 63.7318 | 63.7318 | 496.979 | 433.248 | 4219.275 |
| **17** | 2027 | 0 | 63.7318 | 63.7318 | 507.858 | 444.126 | 4663.401 |
| **18** | 2028 | 0 | 63.7318 | 63.7318 | 519.048 | 455.316 | 5118.717 |
| **19** | 2029 | 0 | 63.7318 | 63.7318 | 530.210 | 466.479 | 5585.196 |
| **20** | 2030 | 0 | 63.7318 | 63.7318 | 541.352 | 477.620 | 6062.816 |

Net Present Value = PRs. 1113.9 million

Internal Rate of Return = 22%

Payback Period = 4.8 years

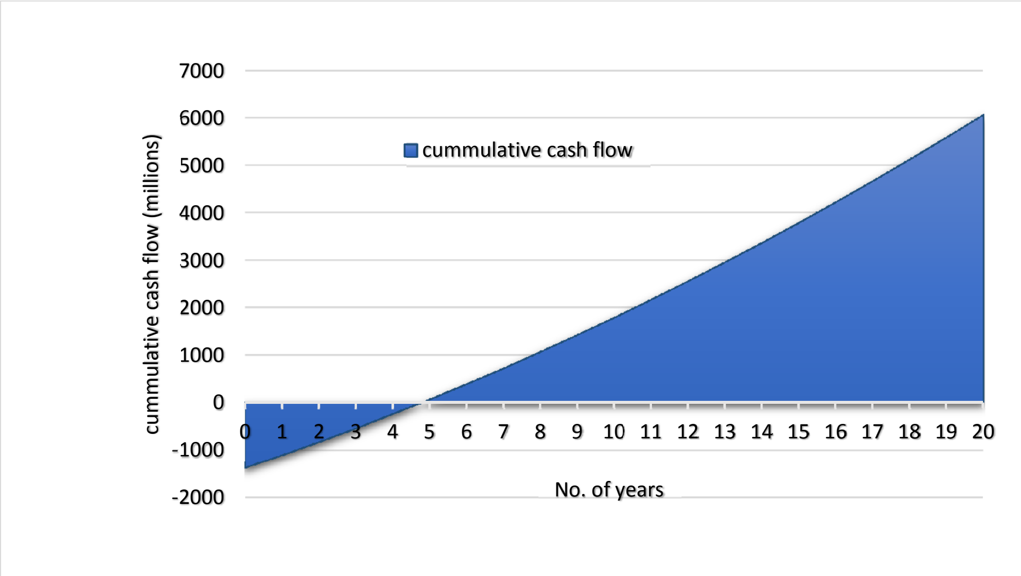


**Fig 4.2: Payback Period (PBP)**

### 4.4.1 Benefit Cost Ratio (BCR)

In order to attain the objectives of the study benefit cost analysis has been conducted to analyse that waste to energy plant is economically feasible or not. BCA is a technique used to investigate the strength and weaknesses of a project and aims to improve economy. It compares the benefit and cost of project before taking investment decision. There are a number of studies in which BCA has been conducted for biogas production projects. It is simple to calculate based on all input costs including capital and O & M cost of AD project. The all-inclusive calculations of BCA is explained in Table 4.4 with the values of discounted benefit and discounted cost of project. The ratio of sum of the values is BCR that is given below at 12% discount rate. The value of BCR is 3.28 which is greater than one means that project is likely to inaugurate. Now the benefit of project is clear and shows that benefit is more than three times higher than cost adequate for analysis and also environment friendly that reduce the liability of land by utilizing waste into biogas.

**Table 4.4: Discounted benefit and cost**

**(PRs. Million)**

| Years | Benefit | Discounted Benefit | Total Cost | Discounted Cost |
|---|---|---|---|---|
| **2010** | 0 | 0 | 1373.46 | 1226 |
| **2011** | 329.804 | 294 | 63.7318 | 57 |
| **2012** | 339.783 | 303 | 63.7318 | 57 |
| **2013** | 349.512 | 312 | 63.7318 | 57 |
| **2014** | 367.938 | 329 | 63.7318 | 57 |
| **2015** | 372.398 | 332 | 63.7318 | 57 |
| **2016** | 385.160 | 344 | 63.7318 | 57 |
| **2017** | 396.738 | 354 | 63.7318 | 57 |
| **2018** | 408.206 | 364 | 63.7318 | 57 |
| **2019** | 419.255 | 374 | 63.7318 | 57 |
| **2020** | 429.175 | 383 | 63.7318 | 57 |
| **2021** | 441.586 | 394 | 63.7318 | 57 |
| **2022** | 452.402 | 404 | 63.7318 | 57 |
| **2023** | 463.398 | 414 | 63.7318 | 57 |
| **2024** | 474.452 | 424 | 63.7318 | 57 |
| **2025** | 485.658 | 434 | 63.7318 | 57 |
| **2026** | 496.979 | 444 | 63.7318 | 57 |
| **2027** | 507.858 | 453 | 63.7318 | 57 |
| **2028** | 519.048 | 463 | 63.7318 | 57 |
| **2029** | 530.210 | 473 | 63.7318 | 57 |
| **2030** | 541.352 | 483 | 63.7318 | 57 |
| **Sum** | | **7777.6** | | **2364.4** |

Benefit Cost Ratio (BCR) = 3.28

### 4.5 Sensitivity analysis

Sensitivity analysis was performed to explore the effect of both the plant capacity and the effect of the value of the capital cost on the overall profitability of project. For this purpose analysis has been performed in wider range and ended with 10 %, 20% and 30 % increase in capital cost. It is executed by using same procedure and same parameters as economic analysis has been done. The purpose of such analysis is to analyse that how sensitive NPV, IRR, PBP and BCR are when initial cost of AD project is going to increase. The initial cost was pondered PRs. 1510.81 million with 10% increase, PRs. 1648.15 million with 20% increase and PRs. 1785.498 million with 30% increase describe separately in all years but O & M cost and discount rate (12%) were kept same. Results have shown that all the economic parameters were sensitive to increase in capital cost of project as given in Table 4.5.

The output of any plant depends on accessibility of inputs. Therefore the capacity of plant vary with cost, discount rate and waste amount. The sensitivity of project could also be seen with change in discount rate. It could be seen in Fig 4.2 that with increase in discount rate the project is no more acceptable. If we compare economic and sensitivity analysis of AD plant, it is shown that if amount of waste is reduced by 5% then value of all parameters change. There would be reduction of NPV, IRR and BCR values and PBP would increase. It is also shown that with 10 % increase in capital cost, IRR value contracts and reaches at 20% meaning that when cost increases, it will lead to reduction in return. The NPV value also reduces and now grasp PRs. 976.5 million and there will be increase in payback period. It means that now it will take more than five years to pay back initial cost of project. Benefit cost ratio will also reduce because when cost increases then return will spontaneously reduce and hence benefit will drop but still greater than three means that return of project will be three times more than its cost.

**Table 4.5: Sensitivity analysis of AD plant**

| Description | Actual Values | Sensitivity analysis with change in capital cost of AD plant | | | Sensitivity Analysis with decrease in waste amount by 5% |
|---|---|---|---|---|---|
| | | Increase in capital cost | | | |
| | | 10% | 20% | 30% | |
| NPV (PRs. Million) | 1113.9 | 976.5 | 839.2 | 701.8 | 965.7 |
| IRR (%) | 22 | 20 | 19 | 17 | 21 |
| BCR | 3.28 | 3.12 | 2.98 | 2.84 | 3.13 |
| PBP(years) | 4.8 | 5.2 | 5.6 | 6.1 | 5.1 |

### 4.6 Environmental Analysis

Waste is considered as major source of environmental pollution. Until now, methane emissions from dumpsites is taking place due to uncontrolled waste disposal. It is important to note that 40%-70% methane emissions from dumpsites is a major gas. e. Global methane emissions from landfills is estimated to increase between 40 and 70 Tg/year and expected to increase further in coming decades if no measures are taken to control it (Savva et al., 2012).

In Pakistan 1.8 % of total GHG emissions are due to waste (PC, 2010). To determine environmental impact it is needed to compare the emissions before production of biogas and after biogas production from MSW of Islamabad. It is noticed that data could be used to calculate environmental performance before and after treatment of organic fraction of municipal solid waste from landfill sites.

It is found from results of present study that if AD process is not occurred then GHG emissions would be 388.42 tons $CO_2$ equivalent on average basis per year. The reduction of GHG has been more important now because it is expected to rise up to 490 tons $CO_2$ eq. in 2030. The calculations of emissions are based on IPCC formula (IPCC, 2001). The results of present and upcoming years are given in Table 4.6 that shows $CO_2$ equivalent emissions per year generated from waste disposed at landfill in Islamabad. It makes AD plant more attractive and sustainable to launch for the waste of Islamabad city. If all the garbage produced is dumped in dumpsites, it will generate GHG emissions shown in Fig 4.3 but after treatment of waste and production of biogas the emissions could be reduced by 58% from dumpsites. Consequently emissions from dumpsites are calculated that could be saved if AD plant is established. In order to remove the negative impact of waste disposed in the dumpsites, AD plant establishment is adequate. The emissions are responsible for strong odour in the area and due to use of this technology its production will also be reduced. In addition, pollution in atmosphere and ground water will be adverse if waste will remain in dumpsites and not managed properly.

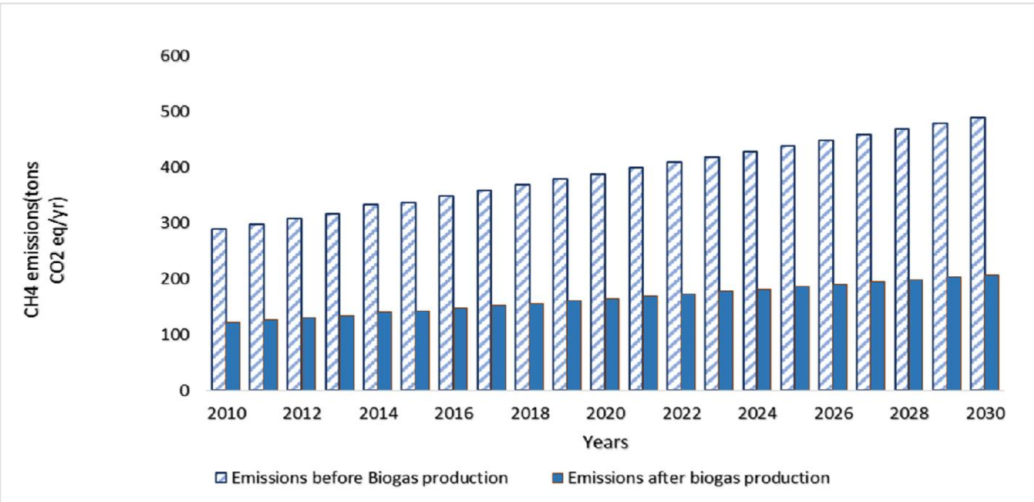


**Fig 4.3: $CH_4$ emissions from dumpsite**

Pakistan ratified as member of UNFCCC in 1994. Clean Development mechanism (CDM) is one of the important mechanism of carbon emission reduction of UNFCCC issued by Kyoto Protocol. It includes both large and small scale projects. Renewable energy and emission reduction projects are included in small scale projects under Kyoto Protocol (Chen et al., 2015). Pakistan can get financial benefit from CDM by reduction of GHG emissions and selling of Certified Emission Reductions (CERs) which is big opportunity for more investment in AD plant. Thus by doing this activity Pakistan can get benefit not only from environmental point of view but also financially.

**Table 4.6: $CH_4$ Emissions from dumpsite**

| Years | Emissions before Biogas production (tons $CO_2$ eq./year) | Emissions after Biogas production (tons $CO_2$ eq./year) |
|---|---|---|
| 2010 | 289.0898 | 122.2982 |
| 2011 | 297.8774 | 126.0158 |
| 2012 | 306.8903 | 129.8286 |
| 2013 | 315.6779 | 133.5462 |
| 2014 | 332.3204 | 140.5867 |
| 2015 | 336.3485 | 142.2908 |
| 2016 | 347.875 | 147.1671 |
| 2017 | 358.3321 | 151.5909 |
| 2018 | 368.6902 | 155.9728 |
| 2019 | 378.6697 | 160.1946 |
| 2020 | 387.6289 | 163.9848 |
| 2021 | 398.8385 | 168.7269 |
| 2022 | 408.6078 | 172.8598 |
| 2023 | 418.5394 | 177.0613 |
| 2024 | 428.5227 | 181.2847 |
| 2025 | 438.6445 | 185.5667 |
| 2026 | 448.8699 | 189.8925 |
| 2027 | 458.6955 | 194.0492 |
| 2028 | 468.8018 | 198.3246 |
| 2029 | 478.8845 | 202.5901 |
| 2030 | 488.9471 | 206.847 |
| Average | 388.42 | 164.32 |

### 4.7 Discussion

The basic aim of this study is to analyze amount of energy from OFMSW and to check the economic and environmental benefit of AD plant. Biogas is an attention-grabbing part of producing electricity. The performance of 2370 cubic meter volume of AD plant used in this study proves that with increase in population electricity production rate will increase by 59% from organic streams in future. The useable electricity production is 104973.4 kWh per day. For sale of electricity PRs. 11.22 per kWh tariff is used (NEPRA, 2014-15). Analysis shows that AD is economically and environmentally practicable and probable to inaugurate in capital territory of Pakistan. The use of AD project is also doable by other economists and environmentalists. Economic analysis of this study is based on NPV, IRR, PBP and BCR which could be compared by economic analysis of different AD plants used in other studies. Economic parameters used to check the feasibility of AD plant and their comparison with other studies are given in Table 4.7. The NPV results given in the table are mostly less than that of NPV obtained in this study that is PRs. 1113.9 million. The IRR value analysed in this study is 22 % which is more than 20% and 16 % as obtained by Karellas et al., (2010) and Van Deal at al., (2013) demonstrating promising result. Payback period should be less to detain profit rapidly. The PBP result of this study is 4.8 years, which is quite suitable for project and less than most of the reference plants given in Table 4.7.

Anaerobic digestion (AD) is very promising solution of waste and this technology can mark a noteworthy contribution towards renewable energy in Pakistan. In developing countries mostly, small reactors of AD using manure and OFMSW are installed. By AD process majority of biogas can be produced from OFMSW that can lead to efficient energy and hence electricity production and safe environment. Pakistan is an agricultural country that’s why it is rich in biogas assets and can save money by using biogas resources. Friedrich & Trois (2011) analysed that from last few decades there are series of technologies for waste management in developing countries, which have been introduced but they are no longer sustainable in long run, however, AD shows real potential. The value of this study comes out as economic and environmental benefit after emission reduction from dumpsites. There are majority of studies focused on landfills in which GHG emissions have been calculated.

**Table 4.7: Economic analysis of AD plants**

| **Author** | **Years** | **Country** | **Waste type** | **Plant size/ capacity** | **Economic tools** | **Findings** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **NPV** | **IRR %** | **BCR** | **PBP yrs.** |
| **Akbulut** | 2012 | Turkey | Cow manure, sheep dung | 2713 $m^3$ | PBP NPV | €27.74 million, | --- | --- | 3.4 |
| **Ali et al.** | 2012 | Thailand | Food | 100 ton/day | BCR PBP | ---- | --- | 3.37 | 2 |
| **Karellas et al.** | 2010 | Greece | Agricul-ture | 1000-5000 $m^3$ | NPV IRR PBP | 3,812,745 € | 20.2 | --- | 10 |
| **Chanekarn et al.** | 2015 | Thailand | Waste-water, Elephant grass, Decanter cake | 3500 $m^3$ | NPV IRR PBP | 81.37 THB | 29.9 | --- | 13.6 |
| **Van Deal et al.** | 2013 | Netherland | OFMSW | 64000 ton/yr. | Techno economic evaluation | 11,378,112 € | 16 | --- | 5.7 |
| **Gbrezgabher et al.** | 2010 | Netherland | Livestock manure | 70,000 ton/yr. | NPV IRR | €4195000 | 21 | --- | --- |
| **Present study** | 2016 | Pakistan | OFMSW | 23760 $m^3$ | NPV IRR BCR PBP | PRs. 1113.9 million | 22 | 3.28 | 4.8 |

Liu et al., (2012) estimated GHG reduction from landfill reaches to 114 $CO_2$ eq./t for AD plant of 1.8 million tons waste capacity using IPCC method. Jarmillo & Matthews (2005) estimated that US emitted about 659 million methane from landfill. Kennedy et al., (2010) also used IPCC method for calculation of GHG emissions from landfills attributable to ten cities and recognizing that emissions would be released for many coming years if not mitigated.

Finally, it can be noted that biogas can be produced using AD technology from OFMSW in large quantity and also its economic and environmental aspects are promising. It is noteworthy that the project is beneficial and feasible in all point of views studied in this study. This study also contributes energy resources in research and development from future perspective of Pakistan. Mostly wind and solar are used for production of renewable energy but they are not enough to fulfil energy demand and shorten the energy crisis. Therefore, for bridging the gap of energy requirement in Pakistan, there is need to increase dependence on renewable energy that is sustainable and reliable.

# Chapter 5

# Conclusion and Policy Recommendations

## 5.1 Introduction

This chapter comprises of two parts. First is of conclusion and second is policy recommendations and implications.

## 5.2 Conclusion

This study focuses on environment and economic benefit of conversion of organic fraction of municipal solid waste of Islamabad into renewable energy using anaerobic digestion technique. It is concluded that biogas technology can make a significant contribution in mitigation of environmental degradation as well as sound in economic point of view. Biogas from OFMSW to generate electricity could reduce energy crisis. The process of AD provides environmentally safe digestate. AD plant is not only environment friendly but also reduce the financial burden. To find out economic viability NPV, IRR, BCR and PBP has been used and for risk assessment of project sensitivity analysis has been concluded. It is found from economic valuation that AD project is sound for energy generation. The benefit of project exceeds cost and hence proved as cost effective project. So, alternative hypothesis has been accepted and null hypothesis has been rejected, which leads AD to sustainable waste management option and is considerable for production of renewable energy in Islamabad. Finally, it is now possible to conclude that AD is technically and economically feasible project. The decisions maker can guide investors to invest in this project in future.

## 5.3 Policy recommendations/ implications

The present study has following implications and recommendations are also given below:

- Waste to energy results in minimum waste at disposal sites.
- It will bring a strong profit and healthy change in economy of Islamabad.
- AD is economically feasible and has great incentive for private investors to invest in this project.
- The process of AD is largely fenced therefore the looming for odour and dust nuisance is substantially reduced.
- It will generate clean and green energy and reduce GHG emissions to large extent.
- Planning guidance whether constitutional or consultative are needed to better address the climate change mitigation agenda in order to meet renewable energy demand.
- As the waste review has identified, anaerobic digestion apprehends the greatest environmental benefit of treatment option for food waste, so should make the best use of waste resources should be used.
- The government should provide technical trainings for basic skills and operation of plant.
- The participation of NGOs is necessary in SWM practices.
- To cope biogas production in a sustainable manner, there is a need for further research in the different areas including higher degree of public understanding achievement and considerate about beneficial use of biogas, developing cost-efficient and effective conversion technologies for direct energy recovery from bio solids, advancing technology for biogas production and selecting or upbringing resource for efficient biofuel production.
- Public awareness strategy should be established to reduce open waste storage sites so that emissions could be reduced.
- Capacity building and institutional strengthening is needed for construction and operation of sanitary landfills.

- Every developing country should develop its own solid waste management policy that best suits its economy and environment.
- Waste management strategy should start with construction of more AD plants in Islamabad as it is an alternative source of fuel with positive outcomes.

### 5.4 Limitations and future research

The study is focused on urban areas of Islamabad city and based on dry mesophilic AD technology of waste management. The study is based on existing data provided by CDA. Future research in this direction will identify the collection of primary data of waste generation of Islamabad. Wet mesophilic AD technology could be used for future research or other waste management technologies including recycling, incineration and its environmental and economic effects on economy could be studied as well.

However, it is hoped that results derived from the study will help in future research and to relieve our country from energy and environmental crisis.

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# Appendices

## Capital cost, O & M cost and Economic Analysis of AD plant (Dry, mesophilic) from Organic Fraction of Municipal Solid Waste

## (160,000 ton/yr.)

**Appendix A**

**Plant Capital Cost Estimate**

**PRs. million**

**General Site Works**

Total Land = 15 acers (3.5 acres for digester+ 10 acres for Waste Processing + 1.5 acres for Roads, Buildings etc.)

Total Land = PRs. 57.6 million (PRs. 3.84 million/acer)

General (clearing, dewatering, geotechnical investigations, etc.) = PRs. 1.5 million

Roadworks, paving, roadway lighting, signage, fencing/gates = PRs.4.8 million

Storm water management = PRs. 3 million

Utility connections, buried piping (sewer, gas, water) = PRs 1.5 million

Other Expenses = PRs. 0.60 million

**Sub Total: 69**

**New Buildings**

Tip floor (2000 $m^2$ x Rs.24, 000/$m^2$) = PRs. 48 Million

Pre-Processing, dewatering Building (1000 $m^2$ x PRs. 30,000/$m^2$) = PRs. 30 million

Wet Processing Building (2000 $m^2$ x Rs.30, 000/$m^2$) = PRs. 60 million

Other (admin areas, electrical/mechanical, maintenance, laboratory, etc.)

Scale house and 2 scales, Miscellaneous structures (at tanks, etc.) = PRs. 72 million

**Sub Total: 210**

**Major Tankage (including foundations)**

Digesters

Gas Storage Tank

Liquid (feedstock) Storage Tank

Process water storage tank

(Cost of daily 1 $m^3$ digesters = PRs. 7000)

**Sub Total: 419.893**

**Pre-Processing Equipment**

Trommel screen, Comminuting drums

**Sub Total: 48**

**Main and Post-Processing Equipment**

Feed pumps, mixing units, conveyors

Screw Presses (2), centrifuge

Vibrating Screen

Other process piping, valves, pumps, small tankage

**Sub Total: 210**

**Flaring and Odour Control**

Flare and gas trane

Biofilter (concrete walls, media support, media, etc.)

Blower, ducting, humidity control, other controls, etc.

**Sub Total: 18**

**Electrical and Steam Generation**

Steam Generation package (digester preheating)

Electrical Generation package - Engine Generator Set ($2,200/kW x 5321.57kW)

**Sub Total: 330**

**Miscellaneous**

Residue compactor, bins, containers

Platforms, catwalks, ladders, other misc. metal works

Wastewater treatment package allowance

**Sub Total: 60**

**Others**

Registration fees with AEDB (PRs. 10,178)

Registration with PPIB (PRs. 20,355)

Processing fees for issuance of letter of support to PPIB (PRs. 8,142,000)

Licence fees submitted to NEPRA (PRs. 400,000)

**Subtotal: 8.5725**

**Grand Total = 1373.46**

## Appendix B

## Plant Operating & Maintenance Cost Estimate

**(PRs. million /year)**

**Staff Requirements**

1 Plant Manager (80k)

5 Process Control Operators (50 k)

4 Tip Floor Operators (40 k)

4 Maintenance Technicians (40 k)

4 Scale House Operators (30 k)

1 Reception (25 k)

1 Marketing Mgr. (35 k)

12 General labourers (15 k)

1 lab technician (30 k)

**Sub Total: 12.48**

**Utilities and Fuel**

Fuel for rolling equipment (2 vehicles x 10 L/hr x 16 hrs/d x 300 d/yr. x PRs. 75.3/L)

= PRs. 7228, 800/ year

Water (assume water is free of cost)

Electricity (assumes parasitic load addressed through on-site power generation)

Start-Up Natural Gas (assumes biogas used to satisfy heat loads)

**Sub Total: 7.2288**

**Maintenance**

Equipment (17.2 M, 4%)

Buildings and Site Works (2.325 M, 0.5%)

Tankage and Odour Control (4.498 M, 1%)

**Sub Total: 24.023**

**<u>Others</u>**

Rolling Equipment Leases and maintenance

Wastewater Treatment

Lab analysis costs

Administration, Legal, Accounting costs

Service Contracts

Product haul and Tip Fees at Curing Site

Residue Disposal (10% residue assumed)

Greenhouse gas credits

**Sub Total: 20**

**Grand Total = 63.7318**

## Appendix C

## Economic Analysis: Input Assumptions and Data

**Annual Mass Material Balance**

Input Quantity to facility 281564.4 tons

Tons used to Digestate (OFMSW) 162181.1 tons (57.6 %)

**Unit Prices**

Tariff for sale of electricity PRs. 11.2239/kWh

Biogas PRs. 8.5/$m^3$

Electricity PRs. 3.4/kWh

**Annual energy balance**

Gas generation rate 135m3/ton Mass Balance, $m^3$ gas/ton OFMSW

Biogas $m^3$ 21894451 m3

Gross Electrical Output Power 54736127.5 kWh at conversion rate 0f 2.5 kWh/m3 biogas

Electricity used for plant operation 16420838.24 kWh 30% of total

Net Power Output 38315289.22 kWh

Electricity available for sale 1596470.384 kW assuming 24 hrs and 300 working days

**Facility Costs**

Annual O & M Costs PRs. 63731800 See Appendix B

Annual O & M Grant -

Net O & M Costs PRs. 63731800

Capital Costs PRs. 1373460000 See Appendix A

Capital Grant -

Net Capital Cost PRs. 1373460000

**Capital Financing**

| | | |
|---|---|---|
| Plant Period | 20 Years | Used to calculate annual charges |
| Annual capital charges | PRs. 68673000 | |
| Discount rate | 12% | Used for economic analysis tools |

## Appendix D

## Estimated Annual values on basis of 2014 data

**Annual Biogas Production**

Amount of waste generation = 660 tons (CDA, 2014)

OFMSW = 380.16 (57.6% of total waste)

Biogas produced = 380.16 × 135 $m^3$ = 51321.6 $m^3$ /day

**Plant size**

Plant size = amount of waste × retention time

= 380.16 × 25 (at 25 days retention time)

= 9504 tons / day

Dry matter (DM) = 2851.2 tons (30% of total waste)

Wet matter (WM) = 6652.8 tons (70%)

Need to add water to minimize its DM to 15% = 2851.2 × 100/15 = 19008 $m^3$ (One ton material (DM + WM) = 1$m^3$ reactor)

Working volume of digester = 19008 $m^3$ (80%)

Total volume of digester = 19008 × 100/80

Digester size = 23760 $m^3$

**Unit cost of biogas production**

Annual capital cost + Annual O&M cost

68.673m + 63.7318m = 132.405m

Cost of Biogas = Annual biogas production / 132.405 = PRs. 7.1/ $m^3$

**Energy generation from biogas**

Calorific value = 1 $m^3$ biogas × 6 kWh

51321.6 × 6 = 307930 kWh /day

Electricity generation = 1 m3 biogas = 2.5 kWh

51321.6 × 2.5 = 128304 kWh /day

Electricity available for sale = 89812.8 kWh/day (30% used for plant operation)

Annual electricity = 32781672 kWh

**Methane production from landfill**

CH4 emissions (Gg/yr) = [(MSWT • MSWF • L0 ) – R] • (1 – OX)

$MSW_T \times MSW_F = 660 \times 365 = 240.9$ Gg/ year

$CH_4$ (Gg/year) = $240.9 \times 1.0 \times 0.6 \times 0.16 \times 0.77 \times 0.5 \times 16/12$

= 11.872 Gg/ year

$CH_4$ Gg/ year = $11.872 \times 28 = 332.40$ tons $CO_{2\ eq.}$ / year