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Institute for Water and energy Sciences (Incl. Climate Change)

Techno-Economic Assessment of a Combined Heat and Power Technology based on a Reciprocating Gas Spark Ignition Engine in Waste Water Treatment Plant of El Karma, Oran, Algeria.

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Master in ***Energy Policy track***

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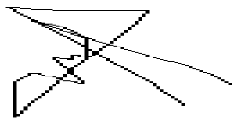
DECLRATION

I hereby declare that "Techno-Economic Assessment of a CHP (Combined Heat and Power) also defined as a cogeneration Technology based on a Reciprocating Gas Spark Ignition Engine in Waste Water Treatment Plant of El Karma, Oran, Algeria" is in partial fulfilment of the requirement of the Master of Energy Policy, it is an original work done by me and has not been submitted to any other University/Institution for the award of any other degree or diploma.

Signature:



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ABSTRACT

This study concerns energy analysis in the waste water treatment plant (WWTP) of El Karma in Oran which is the largest municipal wastewater treatment plant in Algeria and second largest in Africa. This plant is designed to treat 270,000 m^3/day of waste water. It is, also, equipped with four digesters, each of 9,600 m^3, to produce up to 324,000 Nm^3/month of biogas. The plant covers its electricity needs from the network. Most of the produced biogas is burned in a boiler to generate heat for the anaerobic digestion and the remained biogas is flared.

The aim of this study is to assess the viability of a cogeneration in this plant using the whole amount of biogas produced. Cogeneration, also called combined heat and power (CHP), is an efficient approach for generating electric power and useful thermal energy for heating or cooling from a single fuel source with high efficiency.

The investigation is conducted in the case of a CHP technology based on a gas spark ignition engine. The techno-economic performance of the CHP is compared to the current energetic situation of the plant.

The methodology applied uses technical and economic inputs from the biogas plant as well as the CHP. The most important parameters retained in the economic appraisal of the CHP technology are the following: Payback Period (PBP), Net Present Value (NPV), Internal Rate of Return (IRR), and Profitability Index (PI) using two alternatives (constant and escalated costs of energy, amount of biogas produced and operating/maintenance)

The results show that the energy output of the CHP meets the electrical and thermal needs of the plant with an excess in electricity production as the bulk source of income for the plant.

The outcome of the techno-economic assessment indicates that the project is profitable (PI = 2.5) with a short payback period (PBP = 5 years) and interesting internal rate of return (IRR = 18%).

This study clearly emphasizes how CHP, as a technological innovation, can impact the economic viability of WWTP El Karma by building an energy integrated system and saving money.

Keywords: Combined Heat and Power Technology- Reciprocating Engine- Techno Economic Analysis Module- Net Present Value-Internal Rate Of Return - Payback Time-Profitability Index.

ABSTRAIT

Cette étude porte sur l'analyse de l'énergie dans la station d'épuration des eaux usées (ELTP) d'El Karma à Oran, la plus grande station de traitement des eaux usées municipales en Algérie et la deuxième plus grande en Afrique. Cette usine est conçue pour traiter 270 000 m3 / jour d'eaux usées. Il est également équipé de quatre digesteurs, chacun de 9 600 m3, pour produire jusqu'à 324 000 Nm3 / mois de biogaz. L'usine couvre ses besoins en électricité du réseau. La majeure partie du biogaz produit est brûlé dans une chaudière pour générer de la chaleur pour la digestion anaérobie et le biogaz restant est évasé. L'objectif de cette étude est d'évaluer la viabilité d'une cogénération dans cette usine en utilisant toute la quantité de biogaz produite. La cogénération, également appelée chaleur combinée (CHP), est une approche efficace pour générer de l'énergie électrique et une énergie thermique utile pour le chauffage ou le refroidissement à partir d'une seule source de carburant à haute efficacité. L'enquête se déroule dans le cas d'une technologie CHP basée sur un moteur à allumage par étincelles à gaz. La performance techno-économique de la cogénération est comparée à la situation énergétique actuelle de la plante. La méthodologie appliquée utilise les intrants techniques et économiques de l'usine de biogaz ainsi que la cogénération. Les paramètres les plus importants retenus dans l'évaluation économique de la technologie CHP sont les suivants: période de récupération (PBP), valeur actuelle nette (VAN), taux de rendement interne (IRR) et indice de rentabilité (PI) en utilisant deux alternatives (constantes et Coûts accrus d'énergie, quantité de biogaz produite et exploitation / maintenance) Les résultats montrent que la production d'énergie de la cogénération répond aux besoins électriques et thermiques de l'usine avec un excès de production d'électricité comme principale source de revenus pour l'usine. Le résultat de l'évaluation techno-économique indique que le projet EST rentable (PI = 2, 5) avec une courte période de récupération (PBP = 5 ans) ET un taux de rendement interne intéressant (IRR = 18%). Cette étude souligne clairement comment la CHP, en tant qu'innovation technologique, peut avoir une incidence sur la viabilité économique de la station d'épuration El Karma en créant un système intégré d'énergie et en économisant de l'argent.

Mots-clés: Technologie combinée de la chaleur et de l'énergie - Moteur réciproque - Module d'analyse économique Techno - Valeur actuelle nette - Taux de rendement interne - Indice de rentabilité - Profitability Index.

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LIST OF ABBREVIATION

AD	**Anaerobic Digestion**
NACC	**National Agency of Climate Change**
NWMA	**National Waste Management Agency**
BPR	**Biogas Production Rate**
CHP	**Combined Heat and Power**
DBR	**Development of Biological Resources**
CCPT	**Center for Cleaner Production Technologies**
EPA	**Environmental Protection Agency**
GDP	**Gross Demotic Product**
GTZ	**German Technical Cooperation Agency**
HHV	**High Heating Value**
IRR	**Internal Rate of Returnee**
IPCC	**Intergovernmental Panel for Climate Change**
ICEM	**Internal Sectorial Council of Energy Management**
LHV	**Low Heating Value**
MSW	**Municipal Solid Waste**
METAP	**Mediterranean Environment Technical Assistance Program**
NPV	**Net Present Value**
OWASA	**Orange Water and Sewer Authority**
ONEDD	**Environmental and Sustainable Development**
PBP	**Pay Back Period**
NPA-ACC	**National Plan of Action and Adaptation to Climate Change**
NPAE-DD	**National Plan of Action for the Environment and Sustainable Development**

RENAC	**Renewable Academy**
REDC	**Renewable Energy Development Center**
SDC	**Swiss Agency for Development and Corporation**
SBP	**Specific Biogas Productivity**
TPAD	**Temperature Phased an-Aerobic Digestion**
UTO	**Useful Thermal Energy Output**
WWTP	**Waste Water Treatment Plant**

CHAPTER 1. INTRODUCTION

Outlines

1. Introduction.
2. Statement of the Problem.
3. Study Area.
4. Objectives (main and specifics).
5. Organization of the Thesis.

1.0. Introduction

This section presents the current status of the energy and water sectors in Algeria, with the impact of the reliance on the conventional resources on the economy of the country and also the development of the conventional resources. The key parameters such as energy consumption in waste water treatment plants, energy and water resources and the renewable energy and wastewater treatment programs are highlighted.

1.1. Statement of the Problem

With growing economies and populations, availability of Water and energy resources as well as environmentally sustainable development, represent the major challenges faced by nations (Igoud S., et al., 2015). An excessive exploitation of the earth's natural resources caused a lot of environmental problems such as air, water and soil pollution (Igoud, S., et al., 2015). Furthermore, all over the world, people become aware of the environmental and economic consequences induced by the lack of water resources and increasing energy demand. And, to counter these threats, significant investments have been made in both sectors to satisfy the domestic.

In the field of clean water supply, Water are placed at the heart of energy and economy policies in Algeria. Algeria is set to construct over one hundred wastewater treatment plants which will see the country reach over 272 units by the end of 2015-2019 to face water scarcity in the country, although this strategic policy is imperative to secure water resources, the plan will significantly increase electricity consumption and management costs in the wastewater treatment sector (constriction review, 2015). Moreover, this will induce important environmental damages, especially concerning the greenhouse gas (GHG) emission because of the significant electricity consumption generated by natural gas. The situation becomes more complex if the water– energy nexus is considered, because the increase in water demand is positively correlated with the energy consumption.

From the other hand, SONELGAZ, the solely electricity distribution utility in the country has devoted enormous efforts to cover almost 99% of the population needs, However, during the past summers many provinces across the country experienced power shortages due to increasing electricity demand.

The Algerian government launched a program to switch domestic consumption to renewable energy. This program saw a first phase dedicated to the achievement of pilot and test projects of the different available technologies.

As the scientific debate about the energy turn towards energy efficiency and renewable energy systems moves forward, the search for new renewable energy resources and innovative technologies accelerates.

Recently, energy generation from wastewater, e.g., due to heat recovery, attracts more attention internationally and several practical applications are documented in the international literature. In a few countries as, for instance, Switzerland and Germany this energy source is already included in energy policy making (Neugebauer G., et al., 2015). The Austrian implementation of the European Directive 2012/27/EU on energy efficiency explicitly names heat recovery from wastewater as a measure to reduce final energy consumption.

Case studies show that the wastewater treatment plants could harness and contribute that energy and eliminate its net-consumption, with generating excess energy for other uses at a competitive price and contribute for reducing the amount of natural gas used for generating electricity in the grid. In Algeria within the whole water–wastewater cycle, energy demand of wastewater treatment process is high and depends on the location of the plant, its size (population equivalent, organic or hydraulic load), type of the treatment process and the aeration system, effluent quality requirements, age of the plant, and experience of its managers. Electrical energy used is from the grid and used mainly for the operation of activated sludge wastewater treatment plants (in lagoon based wastewater treatment plants (WWTPs) it is used for pumping and sometimes for treatment), for network pumping and for lighting. It is also used for pumping in marine outfalls.

So, it became necessary to place Renewable energies and water at the heart of energy and economy policies in Algeria and guide facilities through an assessment of Algerian current energy performance within WWTPs, and assess renewable energy generation potential there.

1.2. Study Area

Wastewater treatment plant of El Karma, Oran – Algeria:

- The largest municipal wastewater treatment plant in Algeria and second largest in Africa.
- The plant employs mechanical/biological treatment and an additional disinfection step, which prepares the treated water for possible water reuse.

Key Data:

- Location: El Karma, Oran, Algeria
- Capacity: 270,600 m^3/ day

1.3. Objectives

- **Main objective**: To perform a techno-economic analysis regarding an implementation of a CHP technology for generating heat and electricity, this is the main objective of this study.
- **Specific objectives:**
- To estimate WWTP electricity and heat,
- To investigate the potential of electricity and heat from biogas produced in the plant using CHP technology,
- To compare the potential of electricity and heat from biogas using CHP in WWTP plant over the conventional case through two alternative scenarios.

1.4. Organization of the Thesis

The thesis consists of five chapters:

- Chapter 1: the following topics are reviewed: energy and water situation in Algeria, statement of the problem, objectives of the research, and project organization outlines.

- Chapter 2: covers scientific literature on the study including the following headlines: overview on Algerian energy profile, waste water treatment sector in Algeria, anaerobic digestion process, benefits of CHP technology and alternative CHP technologies.
- Chapter 3: represents the methodology and technical analyses module.
- Chapter 4: describes the results and discussion
- Chapter 5: conclusion and recommendation

CHAPTER 2. LITERATURE REVIEW

Outlines

1. Energy situation in Algeria.
2. Algerian wastewater and energy sectors.
3. Energy consumption and generation in WWTPs in Algeria.
4. Anaerobic digestion processing in WWTPs.
5. History and potential of anaerobic digestion process in Algeria.
6. Biogas contents in WWTP El karma.
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8. Combined heat and power technology.
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10. Climate change legislation in Algeria.
11. Algeria executive used portfolio available for CHP project.
12. Benefits of installation of CHP in WWTPs.
13. A case of success CHP project and its techno economic module.
14. Summary.

2.0. Introduction

In the following section, the potential of different renewable energies in Algeria in detail. The location of the case study site with its technical technology and infrastructures characteristics were highlighted. A brief history of anaerobic digestion process, their types and their current status with CHP technologies in order to choose the best technology option. Climate change legislation in Algeria and a success case study of CHP and its techno economic module used for the techno economic analysis.

2.1. Energy Situation in Algeria

Algerian`s economy has negatively been affected by the changing in oil prices on the world market. The economy in Algeria depends heavily on the hydrocarbons resources. In Africa, Algeria is one of the top three oil producers (OPEC member since 1969) and the leading natural gas producer. The oil and gas revenues are the backbone of the Algerian economy and its hydrocarbon-based growth. According to IMF, the EU represents the key export market for both energy sources from 2002 to 2014 (the period of rising oil prices): 86% natural gas exports and 76% of total crude oil are sent to Europe (EPA, 2016) with around 98% of exports earnings were from the hydrocarbons resources, about 69% from fiscal revenues, and 36% of the Algerian`s gross domestic product (GDP) (IMF, 2016). Consequently in 2015, the oil price hits the economy strongly since the oil and natural gas export revenues declined by 41% (Aïssaoui A., 2016). The foreign exchange reserves helped softening the extent of the economic shock, going down from $194 billion in December 2013 to 153$ billion in late 2015.

In addition, energy subsidies and low energy efficiency strongly take part of the unsustainable use of energy resources in Algeria. A failure to meet the increasing in energy demand in Algeria is most likely contributes in a continuous declining in the foreign exports of natural gas (figure 2-1), as before happened in Egypt, where natural gas supply almost has been completely switched from exports to meet the domestic demand . Because oil revenues plummeted, the fiscal position deteriorated significantly in 2015. Hydrocarbon exports fell by nearly the half, giving rise to the currently situation of account deficit sharply. Fiscal savings (figure 2-2) fell to 12.3 percent of GDP. While Reserves declined by US$35 billion (Andrew J. & M. S., 2016).

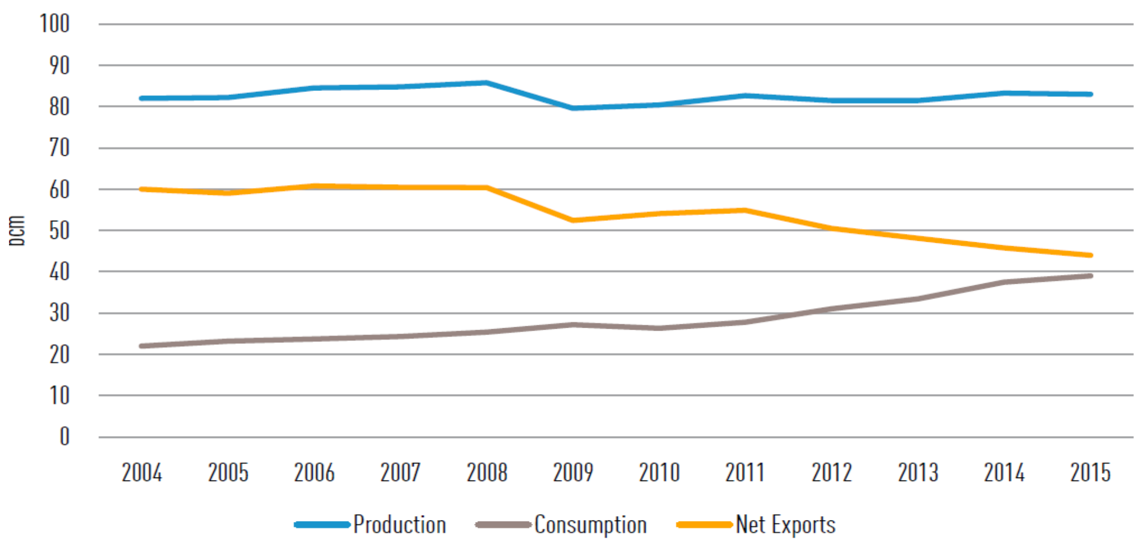


Figure 2- 1: Natural Gas Balances in Algeria 2004 - 2015.Source: Own illustration based on BP Statistical Review of World Energy 2016.

However, from the beginning of 2016 the government started implementing measures to raise prices of fossil fuels and electricity since the price of electricity in Algeria is one of the lowest in the world at 0.035 $/kWh in industrial sector and the natural gas price is 0.00334$/kWh which is due to the major share of the cost being covered by subsidies, in order to ensure smooth running of the country and avoid depletion of the government coffers trying to meet the rapid population growth (in last 15 years the population increased almost by one third reaching nearly 41 million in 2017), urbanization and better living standards that are some of the natural drivers of energy demand (Jekaterina, 2016).

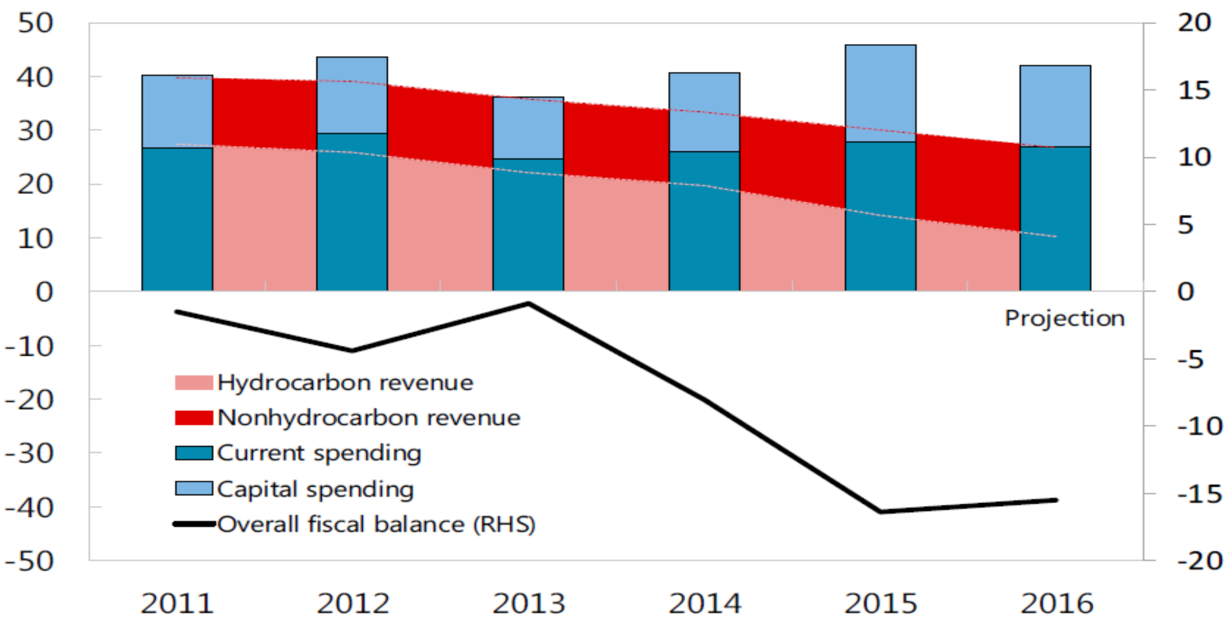


Figure 2- 2: Over fiscal balance in percent of (GDP, 2011-2016). Source: IMF

According to the report released in 2015 by the ministry of energy, the total installed capacity increased in the last 10 years by 230% rising from 7,492 MW in 2005 to 17,238 MW in 2015. Table 2.1 below shows the share of the different sources of energy in the installed capacity of the country. The share of conventional resources in electricity production exceeds 97% of the total generation. However, installed capacity from renewable energies and hybrid systems presents almost a neglected share of 3% (Ministry of Energy, 2015).

Such factors escalade the generation of greenhouse gases, while the international trends advocate for the opposite; less emission, more sustainable and environmental solutions.

Table 2.1: Installed capacity by source

	Gas	**Diesel**	**Hydro**	**Hybrid**	**Renewables**
Installed capacity (MW)	16514	345	172	173	34

Source: (Boudghene S. et al, 2012)

As the conventional energy resources cannot be renewed, relying on them is likely to lead to energy insecurity in the long run. Algerian reserves of fossil fuels and natural gas can only sustain electricity generation for the next 50 years and according to the International Energy Agency, the energy consumption forecast is at an increase of about 53% (Stambouli, A. B., et al., 2012). In addition to that, the current high energy consumption and low efficiency of the systems affect the sustainable development of the different energy sectors in the country.

So, Algeria has drawn a roadmap for the use and promotion of renewable energy encouraged by its commitment to the international community to fight against the global warming backed by the abundance and being one of the greatest countries in solar potential field in the world. Consequently, The Algerian government set up a program, this program has seen its first phase dedicated to the achievement of test and pilot projects of the different technologies, during which pertinent elements in connection with technological evolutions in the concerned sectors appeared in the energy arena and drive to the review of this program (REDC 2015). That review of this program is on the large-scale development of photovoltaic and wind fields, the postponement, to 2021, of the development of the solar thermal (CSP) as well as on the introduction of biomass field (waste valuation) of the cogeneration and geothermal. Achieving this program will allow Algeria to reach by 2030 to have 27% of its electricity from renewables in the national report of electric production. Project tests and pilots were implemented in the first phase of the program in order to identify the different technologies and their response under the climate conditions. Figure 2-3 below shows the share of each renewable energy resource and its planned power capacity installation to which biomass represents only 4% of the total installed capacity.

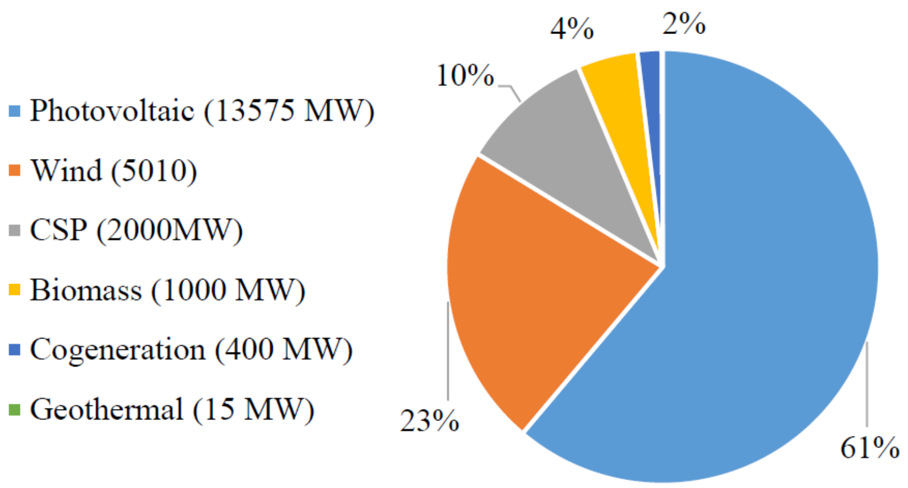


Figure 2- 3: Installed power capacity in 2030. Source: Renewable Energy Development Center of Algeria.

So, the targets per technology are set according to two phases as outlined in the table below:

Table 2. 2: The Algerian RE target (Wikipedia)

Source	**1st phase 2015-2020 [MW]**	**2nd phase 2021-2030 Mw]**	**Total [MW]**
Solar PV	3,000	10,575	13,575
Wind	1,010	4,000	5,010
CSP	-	2,000	2,000
Cogeneration	150	250	400
Biomass	360	640	1,000
Geothermal	5	10	15
Total	4,525	17,475	22,000

To meet the targeted program, it became necessary to guide facilities through an assessment of Algerian current energy performance within the sectors, and assess renewable energy generation potential on these sectors. One of the high energy consumption sector in Algeria is the water sector where water and energy resources availability as well as environmentally sustainable development represent the major challenges faced by nations with growing economies and populations. Furthermore, unrestrained exploitation of the earth's natural resources has already resulted in major environmental problems such as air, water and soil pollution.

2.2. The Algerian Wastewater –Energy Sectors

In Algeria, Water is a rare commodity due to renewable natural water resources are estimated at approximately 15 billion m^3 per year that is almost 500 m^3/ capita/year, which is widely considered as the scarcity threshold that points out developing scarcity and underlying crises. In Algeria, The future development in water sector depends on some solutions characterized by high consumption of energy, such as sea water desalination and wastewater treatment for water reusing. So, development of water sector will therefore be strongly tied to energy sector`s development.

In Algeria, Wastewater Treatment plants are high energy consumption but, from the other hand, WWTPs are considered as an opportunity for the country to guide facilities for renewable energy source through an assessment of their energy performance, and assess its renewable energy generation potential on the site from Sewage sludge that is produced in wastewater treatment plants (WWTPs) as part of the cleaning process. The sludge contains organic particles that are removed from the wastewater, which are rich in organic matter and nutrients, and leaving the water clean for its release and reuse it again.

Energy demand of wastewater treatment process depends on, the size of the plant, the treatment process type and the aeration system, age of the plant, and management of the plant. Similarly, many of the technical processes of harnessing, extracting, and producing consumes energy. That is called the ‘water–energy nexus’ where water and energy are coupled in intimate ways, it has been increasingly considered as an important issue which is necessary to be taken into account for future planning and strategic policy considerations in Algeria (Siddiqi A., &Anadon L. D., 2011).

Years ago, sewage used to be dumped into waterways and a natural process of purification began. First, diluting the sheer volume of clean water happened in the stream wastes. Then, consuming the sewage happened by Bacteria, other organic matter and other small organisms in the water, creating new bacterial cells; carbon dioxide and other products. Nowadays, due to higher populations, increasing volume of domestic and industrial wastewater require the communities to give a helping hand to the nature. There are two basic stages in the treatment process of wastewater which are primary and secondary, which are outlined here.

- In the primary step, where solids are allowed to go through and removed from wastewater.
- The secondary step, where biological processes is taken place and for purifying wastewater.

In Algeria, in the coming decades, the challenge is to face water scarcity, the country will have to carefully manage the resources. Mobilization of non-conventional water resources such as desalination and wastewater becomes a strategic component of future water policy for development of unconventional resources and the management of water demand which will increase the energy consumption of the water sector. This consumption is estimated to reach nearly 12% of the country′s consumption and must be integrated in the country′s energy forecasts. Although, water and energy become in place of Algerian policy, more coordinated planning and action will be consequently required.

2.3. Energy Consumption and Generation in WWTPs in Algeria

In Algeria within the whole water–wastewater cycle, energy demand of wastewater treatment technology is high and depends on the location of the plant, its size (population equivalent, organic or hydraulic load), type of the treatment process and the aeration system, effluent quality requirements, age of the plant, and experience of its managers. Electrical energy is used mainly for the operation of activated sludge wastewater treatment plants (in lagoon based wastewater treatment plants (WWTPs) it is used for pumping and sometimes for treatment), for network pumping and for lighting. It is also used for pumping in marine outfalls.

In Algeria, in some plants, the energy consumption of wastewater treatment process for reuse reach 800 GWh, or 0.7 kWh/m^3 (Stambouli A. B., et al., 2015). In Algeria, in 2010, about 104.32 million m^3 of wastewater was treated (S. Igoud et al;

2015), that consumed around 30,900 MWh of electricity from the grid which costs1.04 million Euros (€) and led to emission of 18,761 tons of CO_2-equivalent.

In 2013, the amount of treated wastewater increased by 35.2% and electricity consumption increased by 45.8% (S. Igoud et al; 2015). It is illustrated that year by year the energy needed in WWTPs is increasing. In order to follow that increase, it was necessary to encourage the potential of renewable energy potential in WWTPs such as biogas production from sewage sludge resulting from primary and secondary wastewater treatment by using anaerobic digestion process (AD) and convert it into electric and thermal energy.

2.4. Anaerobic Digestion Process in WWTPs

Through wastewater treatment process (WWTP) sewage sludge is a part of the water cleaning. Anaerobic digestion (AD) is a natural complex process, in the absence of oxygen, a microbiological process happens that is used to convert the organic matter of a substrate into biogas. As a microbiological process or anaerobic digestion is happened by certain bacterial populations that are existed in the natural environment. (Chen Y. et al., 2008) (Adekunle K. &Okolie J., 2015) (Zupančič, G. &Grilc, V., 2012).

This process takes place naturally in several types of ecosystems and has been technologized in several years of technological development to be an industrial process, first for organic wastes treatment such as (waste water treatment plants) and further for converting biomass to energy. Examples of AD process from nature are organic matter decomposition in the lower deep layers of warm lakes or lagoons, buried organic matter decomposition and cud digestion in cattle (RENAC). Anaerobic digestion (AD) where sewage sludge can be broken down to produce biogas, a methane rich by-product, can be used to produce electricity and heat by implementing combined heat and power (CHP) technology(Siddiqi A. &Anadon L. D., 2011). Anaerobic digestion is defined as a process of controlled decomposition of biodegradable materials under required conditions, the main is that free oxygen must be absent, at suitable temperatures of mesophilic or thermophilic for naturally occurring anaerobic and present of facultative bacteria and Achaea species, that helps converting the inputs into biogas and whole digestate. Anaerobic digestion process is used to treat collected wastes such as biodegradable wastes and sludge from wastewater separately by decreasing volume and mass of the inputs to biogas which is mostly a mixture of methane and some others gases mainly is CO_2 with gases such as H_2S, NH_3 and H_2) as by-products

Biogas produced, which is partially combustible, since one of its main components is methane. The methane is the produced energy carrier that can be used and converted to other forms of energy (electricity and heat). The other main component of the produced gas (biogas) is CO_2.

The process of anaerobic digestion includes many steps that involving the participation of various types of bacteria, which requires different environmental conditions to live and develop. At the same time, the sludge is stabilized and its dry matter content is reduced. There are four key biological and chemical stages of anaerobic digestion (Zupančič, G. D., &Grilc, V., 2012) as in figure 2-4.

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogens

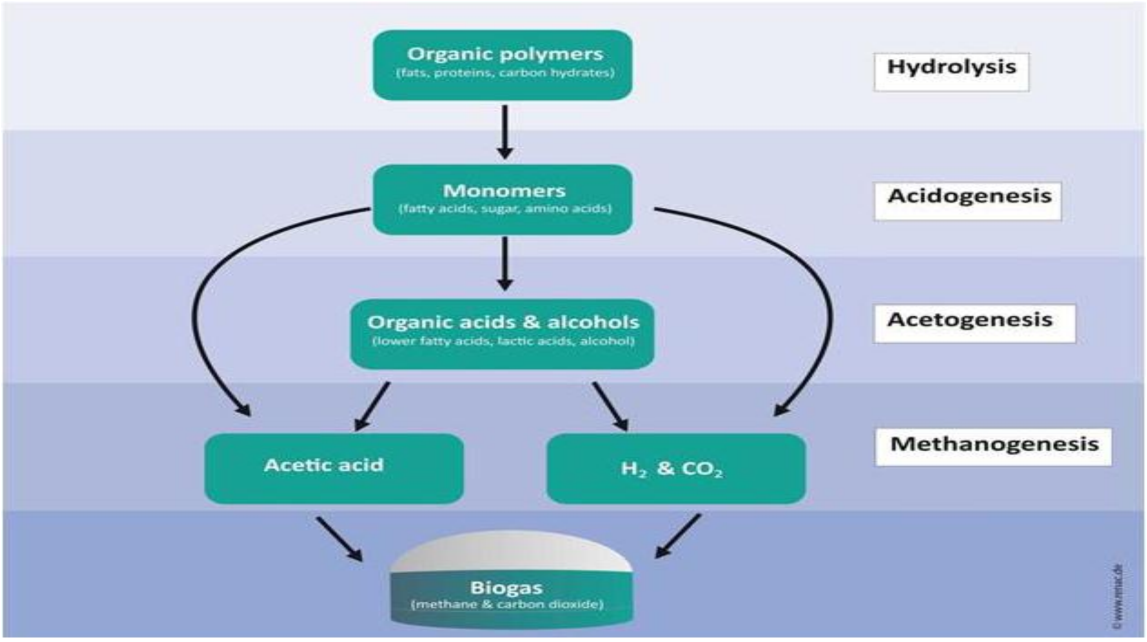


Figure 2- 4: Subsequent steps in the anaerobic digestion process. Source: Biogas Technology and Biomass. RENAC

The benefits of AD of sewage sludge are widely recognized and the technology is well established in many countries. As a result of the AD process, the biogas can be upgraded to bio methane or it can be combusted in a combined heat and power (CHP) plant to generate electricity and heat simultaneously. So, anaerobic sludge treatment process presents an alternative solution with a range of ecological and economic benefits.

- A reduction in organic content of ~50% and conversing them into combustible biogas.
- The production of renewable energy resource,
- The possibility of independent supply of the WW treatment plants with energy,
- Possibility of reducing operating costs,
- A stable and reliable process,
- A smaller footprint of carbon dioxide,
- A reduction in the volume of malodorous substances,
- bacteria reduction and,
- Contributing in Climate protection through an improvement in the CO_2 balance of the treatment plant.

Many of the early generations of biogas plants have being established exclusively for electricity purposes, without consideration for the utilization of the produced heat. Nowadays, the heat utilization is considered as a very important aspect for the economy of the plant as well. In biogas plants, the sale of electricity or using the biogas produced on site alone is not enough for being economically sustainable. This is why the new established biogas plants should include both heat and electricity utilization in the overall plant design.

2.5. History of Anaerobic Digestion Process in Algeria

Late 1930's, digestion of manure was done under the guidance of two teachers of the National School of Agriculture of Algiers where the pre-fermentation is introduced to optimize this microbiologic process. In 1948, construction of a digester in the Institute National Agronomic (higher education school) and start the first experimental car running on biogas (Sadek, I., et al, 2013). In 1949, 840 m^3 tanks were built to produce about 30 000 m^3 of biogas per year and operating up to 1960, using 260 tons per year of manure substrate from livestock of cattle, horses and pigs (Sadek, I., et al, 2013). In 1953, 3 other digester tanks of 14 m^3 were built at the Agriculture School of Guelma for (cooking and heating of the school for 80 people).

Starting in the 80's, the Renewable Energy Development Center (REDC) puts down a program to develop biomass from which several digesters were experimented. In order to optimize the anaerobic digestion, the system was connected to solar water heaters which heat the digesters through heat exchanger and assure a stabilized temperature of 37° C. Another example is a pilot project on a farm in which biogas is produced using manure with stabilized temperature in the digester. The production covers the need for cooking and heating. Currently, these studies are particularly undertaken by the REDC and its research units in collaboration with universities.

2.5.1. Energy generated from municipal solid waste in Algeria

During 2009, the quantity of MSW collected was estimated at 8.5 million tons with an organic matter between 60% and 65% (Sadek, I., et al, 2013). The scenario of the MSW energetic valorization requires first the installation of waste sorting centers for the organic matter recovery then, the installation of industrials digesters for the Methanization of the organic matter of MSW. That would allow producing 1.700 million m^3 of biogas composed by an average of methane between 50% and 70% (Sadek I., et al, 2013). Cogenerating this amount of Biogas would allow to generate 3.5 TWh of electricity and CO_2 emission of 2.04 million. The increase of Municipal solid wastes, in the future, could lead to generate a biggest quantity of biogas and electricity which is estimated at 5.85 TWh in 2020 and 6.82 in 2050. (Sadek I., et al, 2013). On the contrary, the lack of the MSW, could cause GHG emission estimated at 3.36 million tons, in 2020, and 3.91 million tons of CO_2 emission, in 2050. Table 2.3 shows that total MSW collected in Algeria which had an energetic potential to produce 224.82 million m^3 of biogas that can be converted to 607 MWh of thermal energy and 472 MWh of electricity. This amount of energy input could have preserved 270 tons of CO_2 emission. According to the 1.12 million tons of MSW, In fact, that was below the reality because only 80% of MSW was collected (Sadek, I., et al, 2013). So, dimensioned to treat 150000m^3/day of waste water, it might generate up to 41000 Nm^3/day of biogas, that enough to provide 50% of the electricity need of the plant.

Table 2. 3: Renewable energy generation from Algerian municipal solid waste

(Sadek I., et al., 2013).

WWTP Location	Number of municipalities	Biogas (10^6) m^3	Solid waste collected (10^6) m^3	thermal energy MWh	electricity	GHG sequestration
Algiers	07	150.01	30	81	63	36
Bouzareah	04	54.75	11.55	31	24.25	14
Cheraga	04	66.43	13.2	35	27.88	16
Zeraida	05	45.28	9.05	24	19	10
Draria	04	45.26	9.05	24	19	10.9
Birtouta	03	22.1	4.52	12.2	9.49	5.44
Bab Eloed	06	105.85	21.17	57.15	44.45	25.5
HussienDey Bataki	04 04	120.08 97.27	24.01 19.45	64.8 52.5	50 40	28.9 23.44
Bir Mourad	04	103.44	20.68	55.8	43	24.9
El Harrach	03	42.80	8.56	23.11	17	10.3
DarElBeida	06	142.51	28.5	76.9	60	34.33
Rouiba	03	125	25	67.5	52	30.13
Total	57	121.30	224.82	607	472	270.9

In Oran, where biogas produced from 4 digesters is used for only one purpose (heating), this should be changed due to the Algerian government incentive policies for renewable energy use cause it causes economic and environment loose.

2.5.2. Oran El Karma WWTP

In Algeria, for sludge treatment, there are two classic processes that are available: Aerobic sludge stabilisation which takes place in an open sludge tank with injection of air, where sufficient space specifies the prerequisite for its use. The energy requirement of Aeration and agitation is higher than in that case of anaerobic stabilisation. Anaerobic sludge stabilisation – the advantageous solution. Anaerobic sludge stabilisation gives the best solution for sewage plants with a medium to large design capacity starts from approx. 20,000 PE with regard to the cost of energy, efficiency and environmental protection.

Moreover, combustible biogas results from the digestion which can be used for energetic purposes on the plant. A combination of both processes can be involved in the same plant, depending on the individual demands made on the plant where an optimum result can also derive from that dual stabilisation.

The WWTP of El Karma in Oran is dimensioned and installed to treat 270000 m^3/day of waste water of 1,526,000 PE. It is equipped with four digesters each of 9,600 m^3, one 6,800 m^3 gasholder to produce up to 324,000 Nm^3/month of biogas. The characteristics of its technology are the following:

- Mechanical pre-treatment
- Biological treatment with activated sludge process
- Sludge treatment
- Final disinfection
- Thickening
- Anaerobic sludge digestion
- Dewatering

In Algeria, Some other sewage treatment plants with lesser capacities are under construction and the biogas produced is expected to be enough, for most of them, to provide energy for the Plant.

Figure 2- 5: WWTP El Karma. Source: WABAG

2.6. Biogas Contents in WWTP El Karma

The amount of biogas produced in digester completely depends on the efficiency of the anaerobic digestion and its microorganisms. There are two distinct parameters that describe the biogas production from digester (Zupančič G. D., &Grilc, V., 2012).

1. Specific Biogas Productivity (SBP) (it's also called biogas yield). It gives information on how much biogas is produced from the chosen unit of substrate.it is also defined as volume of biogas produced per mass of substrate injected into digester (m^3kg-1). There are differences, SBP can be expressed in m^3 of gas / kg of substrate:

i) Volatile organic solids

ii) Total solids,

iii) (Wet) mass or

iv) COD.

Biogas potential is defines as the possibility of maximum SBP for certain substrate that Biogas potential can be known by a standard method (ISO 1998).

2. Biogas Production Rate (BPR). It is the volume of biogas produced per volume of the digester per day. It gives information on how much biogas we can get from the active volume of a digester in one day. The composition of produced biogas differs in its contents. In most cases, the biogas composition is ranged in table 2.4.

Table 2. 4: Typical composition of biogas (Al Seadi, T., et al., 2008).

Matter	%
Methane, CH_4	50-75
Carbon dioxide, CO_2	25-45
Nitrogen, N_2	<2
Hydrogen, H_2	<1
Hydrogen sulphide, H_2S	<1
Oxygen, O_2	<2

Table 2. 5: Characteristics of anaerobic digester gas (Zuza A., et al., 2015).

Parameter	Digester Gas	
	Range	Value in WWTP El Karma (M. Martinez, 2013)
Methane, CH_4, percent (dry basis)	60 – 70	65
Carbon dioxide, CO_2, percent (dry basis)	30 – 45	30
Nitrogen, N_2, percent (dry basis)	0.2 - 2.5	0.5
Hydrogen, H_2, percent (dry basis)	0 - 0.5	0.2
Water vapor, H_2O, percent	5.9 - 15.3	6
Hydrogen sulphide, H2S, ppmv (dry basis)	200 – 3500	500
Specific gravity (based on air = 1.0)	0.8 - 1.0	0.9

2.7. Utilization of Biogas Produced From Anaerobic Digestion Process

Biogas is a primary energy carrier like the fossil fuels resources. But unlike those, it is not of fossil but of renewable resources from renewable origin. Besides its sustainability consideration, biogas can be used in various ways as an energy carrier to serve for several purposes. Biogas has common advantages with natural gas such as simplicity of transport, storage and conversion to another forms of energy like heat and electricity. Its combustion is less contaminant in comparison with coal and oil fossil fuels, and even the renewable energy sources like wood chips.

Long-developed and well proven technology can use biogas as a renewable primary energy carrier that can be applied almost directly, being the fact that conventional for the use of natural gas with this new kind of energy carrier. Biogas can be used in several ways such as:

2.7.1. Direct combustion and heat utilization

Direct burning of biogas in boilers or burners is the simplest way of utilizing of biogas produced, Biogas is burned for heat production either on site, or can be transported through pipeline to the end users. Biogas does not need any upgrading for heating purpose, and the contamination level does not restrict the gas utilization as much as in the case of other applications. In WWTP of El Karma, biogas is burned in boilers to produce heat for the digesters to keep the temperature at 37 degree. Direct combustion, in natural gas burners, is applied in many countries as well for direct heating purpose.

2.7.2. Combined heat and power (CHP) generation

The standard utilization of biogas from AD in many countries with a development in biogas sector is combined heat and power generation (CHP), as it is considered as a very efficient utilization way of biogas for energy production. Biogas is drained and dried before CHP conversion. Most gas engines have maximum limits for the content of hydrogen supplied, halogenated hydrocarbons and siloxanes in biogas. CHP power plant has an efficiency of up to 90% and produces with 35% electricity and 65% heat (Mudhoo, A., 2012). The generated electricity from biogas can be used as process energy for electrical equipment such as pumps, control systems and stirrers. In many countries like Algeria with high feed-in tariffs for renewable electricity, al the produced electricity is sold to the grid and the process electricity is bought from the same national electricity grid.

Usually, a part of the generated heat is used for heating the digesters (process heating) and approximately 2/3 of all produced energy can be used for external needs (Mudhoo A., 2012), although many of the early generations of biogas plants have being implemented for electricity purposes, without consideration for the utilization of the generated heat and that leads to economic lose.

Nowadays, the heat utilization is considered as a very important aspect for the economy of the plant. For many biogas plants, selling the electricity alone is not enough to be economically sustainable which is why the new biogas plants must include heat utilization in the overall plant design. Figure 2-6 shows Energy flow of CHP unit. There are many types of CHP technology capable of using biogas, but the most used type is the gen-set with heat recovery, i.e. the CHP unit. CHP units can be sized from v kW various electrical power up to several MW.

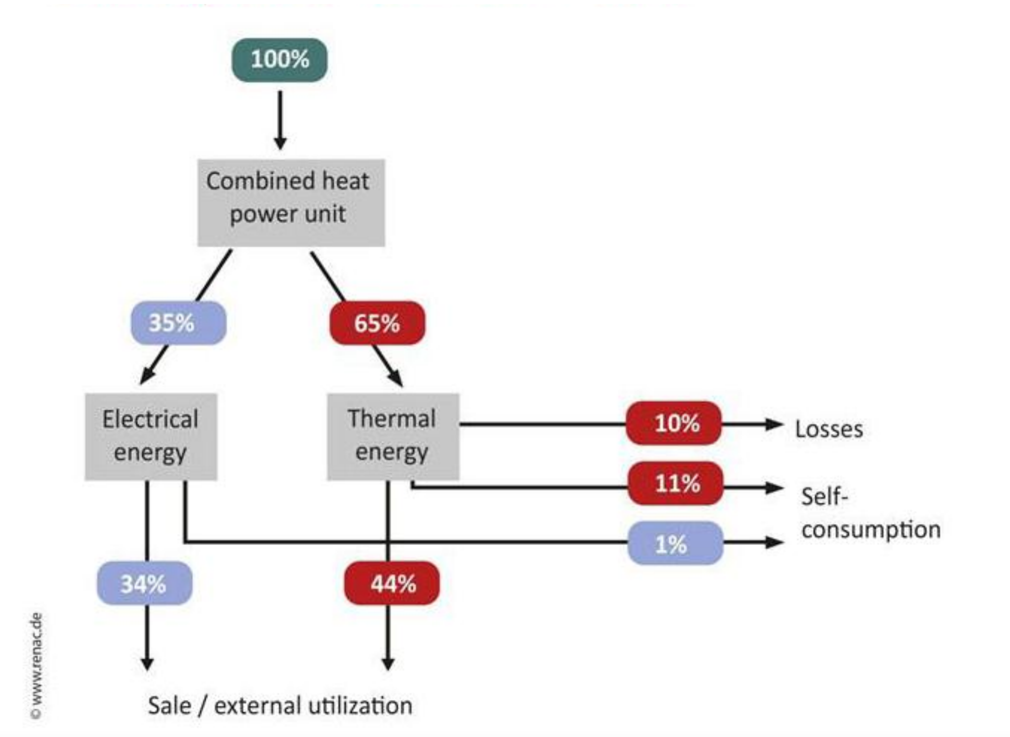


Figure 2- 6: Energy flow of CHP unit. Source: www.renac.com

Smaller CHP unit has a higher thermal efficiency but lower electrical efficiency (around 55% and 35%, respectively), while larger unit can have similar values for electrical and thermal efficiency (42 to 43%) (RENAC).

100% of energy in the form of biogas (methane) is fed into the CHP unit. A standard gas engine used is for producing electricity with an efficiency of around 35% in some cases, the remaining 65% of the energy originally contained is transferred to heat, recovered heat usually at a temperature of around 90°C from the cooling circuit of the plant and from the exhaust gases system (RENAC).

The amount of self-consumption of electricity of a biogas plant is small and can be neglected and consists mainly of auxiliary equipment such as the feeding and stirring system of the reactor and pumps for the cooling circuit of the engine. The generated power available from CHP can be fed into the grid or used by the neighbors of industry or residential. Whereas surplus heat of the plant can be exported via a district heating network to connected consumers. In Algerian potential towards gas engine development as CHP technology is one of the highest among developing countries and certainly the most unexplored yet. Clarke Energy's decision to invest and investigate the country's potential is justified by the 1000 MW+. Clarke Energy will have to overcome many barriers before the gas engine market could expand in Algeria. But its focus on a single product and its worldwide experience in developing and delivering turnkey projects across new territories will be key factor to success. Clarke Energy's ability to deliver best in-class service, coupled with the in-country historical, the capacity of its Jenbacher division to remain world leader gas engine manufacturer will together form the three pillars of a successful trio that is used to team up for growth.

2.7.3. Bio methane for grid injection

Upgraded biogas can be injected into the natural gas grid and distributed, after it has been pushed to the pipeline pressure. In many European Union countries, the access to the gas grid is ensured for all biogas suppliers. There are many advantages of using the gas grid for distribution of bio methane. One of the most important advantage is that the grid connects the production site of bio methane, which is often in rural areas, this helps new customers to get the gas. It is also enables increasing the biogas production at a remote site, without concerns about utilization of excess heat. In this case of Grid injection, the biogas plant needs only a small CHP unit for the process energy or a biogas burner. Many countries like Germany, Sweden, Switzerland, and France currently have standards (certification systems) for injecting biogas into the grid of natural gas. The standards, prescribing the conditions for components like Sulphur, oxygen, particles and water dew point, that have the aim of avoiding bio methane (Al Seadi T., et al., 2008)

2.8. Combined Heat and Power Technology

2.8.1. Technology overview

Combined heat and power (CHP), also defined as cogeneration, is an efficient approach for generating electricity and thermal energy output (UTO) for heating or cooling from a single fuel source. The technology choice for a CHP facility depends on the fuel used and the amount of the capacity needed. Reciprocating internal combustion (RIC) engines are widely used with small and medium applications (under 10 MW) (Shipley et al., 2008). Larger systems use industrial boilers, simple-cycle steam turbines, gas turbines, as well as combined-cycle systems that have a similar design to combined-cycle units used in power production. Useful thermal energy output (UTO) produced by CHP plants is typically in the form of steam and is used in a variety of ways.

Some industrial processes use that thermal energy directly for heating water, or applying it on the boilers and other installations use UTO for creating chilled air or water using an absorption chiller, or dehumidify air using a desiccant dehumidifier, typical use in a commercial installation is space heating (Darrow, K., 2015).

While the technologies and statistics refer to large utility-scale projects, a sizable portion of current is devoted to small-scale CHP, particularly micro turbines compact, lightweight units of 25-500 kilowatts in capacity that can be used at homes or other buildings. CHP systems consist of a number of individual components configured into an integrated whole, prime mover (heat engine), generator, heat recovery, and electrical interconnection. As it is illustrated, CHP system has many advantages, from environmental impact, and an energetic economical point of view. To appreciate such advantages, it is important to compare the energy balances involved. As generally accepted, the efficiency of electrical energy from fossil fuels (traditional power plants) is commonly lower than 40%, whereas it reaches up to 50% for new power plants based on combined cycles (RENAC). From 100 units of energy input, about 40 units of electrical energy are produced. The heat produced by the prime mover with a great part of the heat of the hot exhaust is recovered. In this way, the system efficiency increases up to global values of about 85%, as schematically shown in the following figures.

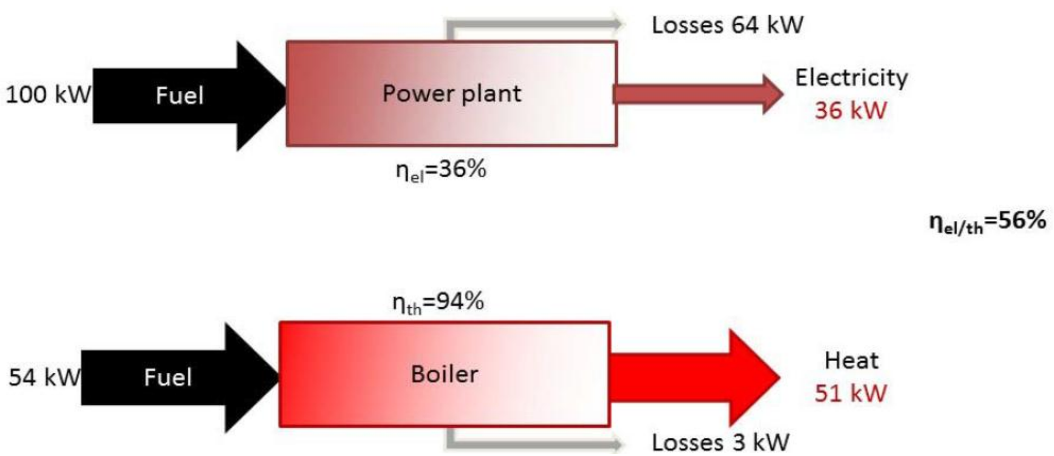


Figure 2- 7: Traditional generation of heat and power, efficiencies. Source: RENAC

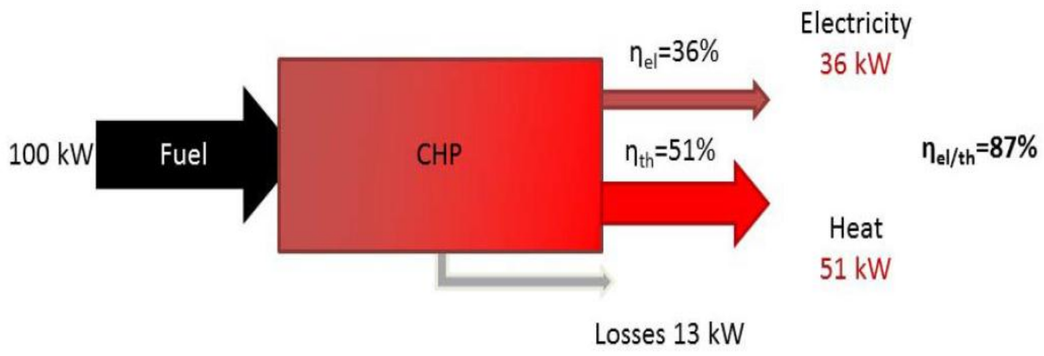


Figure 2- 8: **CHP generation, efficiencies and energy balances.Source. Source: RENAC**

2.8.2. Basic CHP schemes

Generally, a CHP system can be schematized by two main cycles:

- The topping cycle and,
- The bottoming cycle.

According to the figures, in the topping cycle the electricity is firstly produced, and then the heat is recovered to meet the thermal loads of the facility. It is found in facilities which do not have very high process temperature requirements. The basic cycles work as topping cycles are Brayton and Rankine.

On the other hand, in the bottoming cycle the thermal energy is the main product which is produced directly from the combustion of a fuel in the form of steam that covers the process of heating. This cycle is appropriated for industrial applications with require high temperature processes such as steel reheat furnaces, clay and glass kilns and aluminum re-melt furnaces.

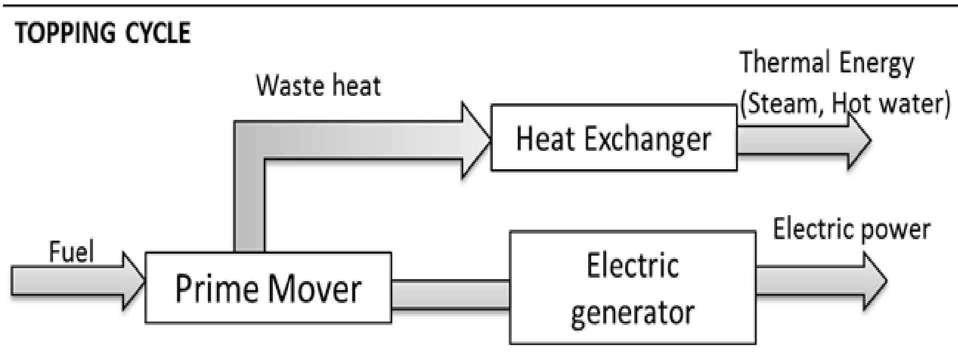


Figure 2- 9: **The topping cycle. Source: IEA, 2008, Energy Efficiency Indicators for Public Electricity Production from Fossil Fuels**

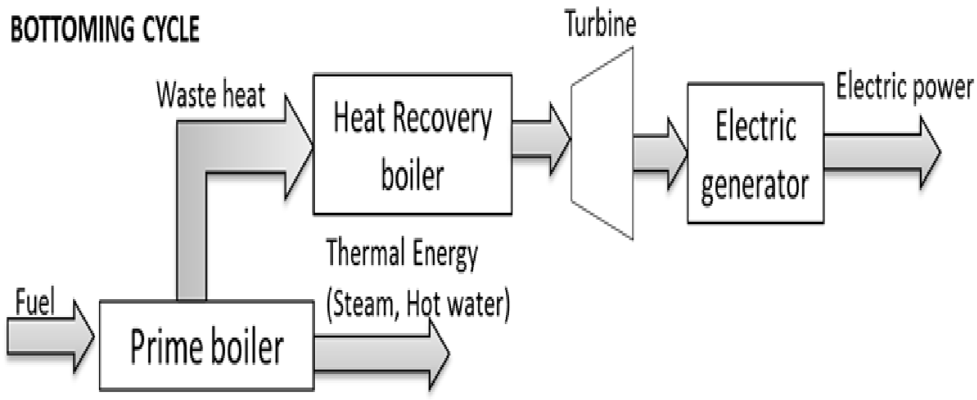


Figure 2- 10: Bottoming Cycle. Source: IEA, 2008

The type of equipment that typically identifies the CHP system and drives the overall system is the prime mover. The purpose of this guide is to provide the stakeholders with a description of the performance and the cost of complete systems powered by prime-mover technologies consisting of (EPA, 2015) (Darrow, K., 2015).

1. Reciprocating internal combustion engines
2. Steam turbines
3. Combustion turbines
4. Fuel cells
5. Micro turbines

2.8.2.1. Reciprocating Engine (RE)

The reciprocating internal combustion engine is the most widely used technology for generating electricity from biogas. The reason is mainly the power and economic feasibility of the system. These engines represent a widespread and consolidated technology, and the associated economic risks are very low compared to other technologies. Gas-fuelled piston engines, also known as internal combustion engine linkages, they are the modified versions of medium- and high-speed engines fuelled by liquid fuels.

Changes in gas engines typically include: changes in the shape of the head and upper part of pistons, additional to gas and liquid fuel system, expansion of the cooling system and the heat exhaust system. There are many manufacturers around the world that produce generators. Major manufacturers, including highly reliable generators and a wide range of products, including Caterpillar (USA) and Jenbache

Energy (Austria), DEUTZ (Germany) and Waukesha (USA) are also worthy of mention.

2.8.2.2. Steam Turbine

Today, steam turbines mainly are used for systems that matched to solid fuel boilers, waste heat of industrial, or the waste heat from a gas turbine (making it a combined cycle). Steam turbines offer a wide offering of designs and complexity to match in demand application and/or performance specifications ranging from single stage backpressure or condensing turbines for low power ranges to complex multi-stage turbines for higher power ranges.

Steam turbines designed to maximize the efficiency of the system for utility service. For industrial applications, steam turbines are single casing design and less complicated for reliability and cost reasons. CHP can be appropriate to both utility and industrial steam turbine designs (Darrow, K., 2015).

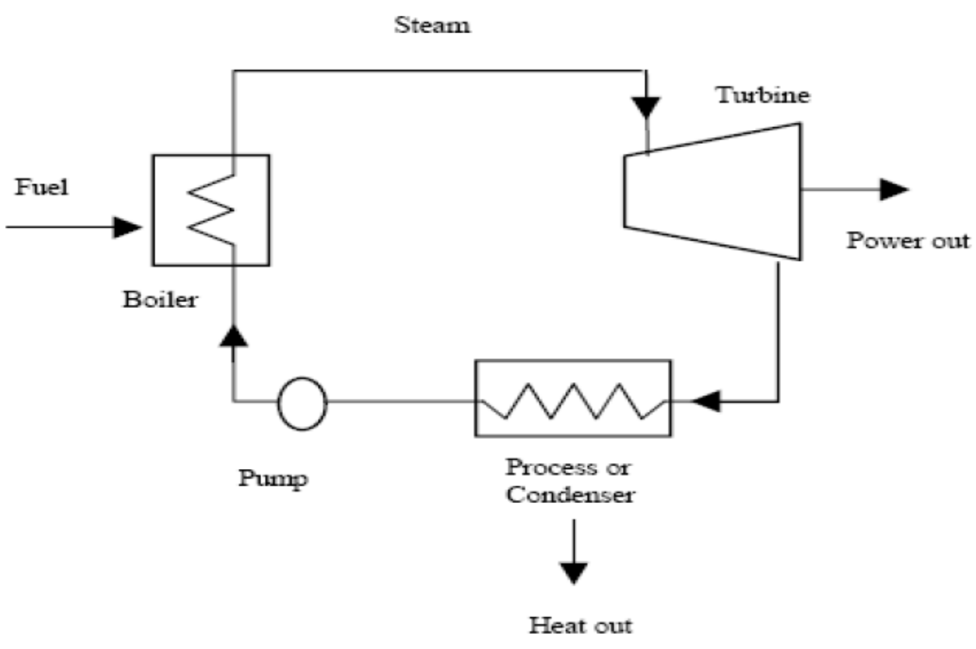


Figure 2- 11: **Simple Steam Turbine Power Cycle. Source: EPA, 2004**

2.8.2.3. Gas Turbines.

Gas turbines have been used for decades in power sector and are often the technology of choice for new electric generation in the world due to their low emissions, low capital cost, and low maintenance. Use of turbines for power generation began in the 1940s and 1950s. The gas turbine is an internal combustion engine that operates with rotational motion. Gas Turbines can be fuelled by natural gas or biogas and are used in various industrial applications that require shaft power. Nowadays, manufacturers are producing more efficient units that are well-suited to distributed generation applications. However, many turbines are already large utility units. Turbines range is in size from 30 kW (micro turbines) to 250 MW (large industrial units) (Darrow, K., 2014). Gas turbines can be used in a variety of configurations:

- Simple-cycle operations.
- A simple cycle of gas turbine with a heat recovery or heat exchanger that recovers the exhausted heat from the turbine and converts it into useful thermal energy.
- Combined-cycle operation: high- pressure steam is generated from recovered exhaust heat and creates additional power using a steam turbine.

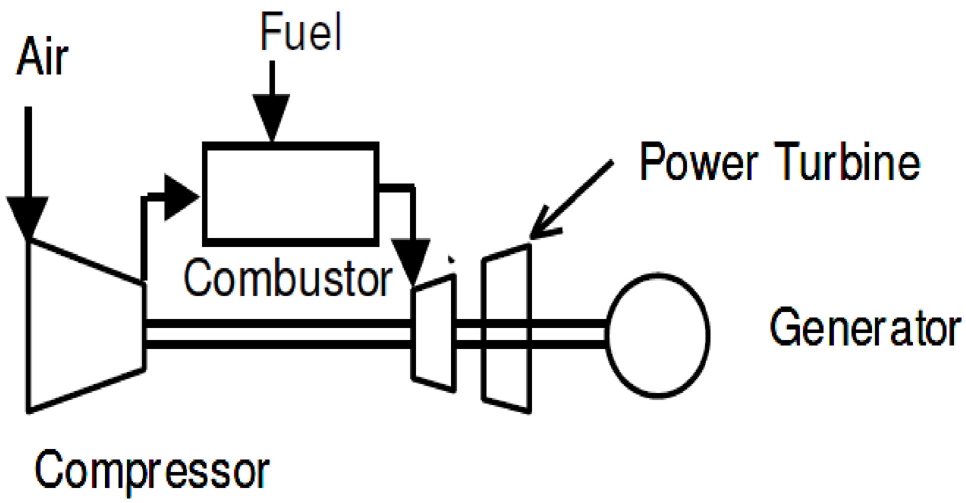


Figure 2- 12: **Components of a Simple-Cycle Gas Turbine. Source: Energy and Environmental Analysis, Inc., 2003.**

2.8.2.4. Fuel Cells

Fuel cell uses an electrochemical or battery to convert the chemical energy of hydrogen into water and electricity. In CHP applications, heat is generally recovered in the form of low-pressure steam (<30 psig) or hot water and the quality of heat depends on the type of fuel cell and its operating temperature. Fuel cells use hydrogen, which can be acquired from natural gas, coal gas, methanol, and other hydrocarbon fuels. Fuel cells are categorized by the type of electrochemical process utilized, and there are several competing types, phosphoric acid (PAFC), proton exchange membrane (PEMFC), molten carbonate (MCFC), solid oxide (SOFC), and alkaline (AFC). PAFC systems are commercially available in two sizes, 200 kW and 400 kW, and two MCFC systems are commercially available, 300 kW and 1200 kW (EPA, 2015). Fuel cell capital costs are high due to low-volume custom production methods, but they are still in demand for CHP applications because of their low air emissions (Darrow, K., 2015).

2.8.2.5. Micro Turbines

Micro turbines are small combustion turbines that can be used in stationary power generation applications. The basic components of a micro turbine are the compressor, turbine generator, and recuperator (a form of heat exchanger in which hot waste gases from a furnace are conducted continuously along a system of flues where they impart heat to incoming air or gaseous fuel). In a micro turbine, the combustion air (air) is compressed using a compressor and then preheated in the recuperator using heat from the turbine exhaust to increase overall efficiency. The heated air and biogas are burned in the combustion chamber and then the release of heat helps the gas to expand.

As the gas expands, it goes through a gas turbine makes the generator works for producing electricity. The size range for micro turbines, available under development, is from 30 to 400 kW (Ismail, M. S., et al, 2013). Micro turbine can achieve electrical efficiency between 25–30 % and total efficiency of 70–90 % (Klobut, K., et al, 2012).

This value requires a recuperator that type of heat exchanger uses the exhaust gases to warm up the inlet air for the turbine. With recuperator a large portion of the exhaust gas is recovered and electrical efficiency can be increased.

Micro turbines can be successfully employed with the biogas with the consideration of how the gas is managed and treated.

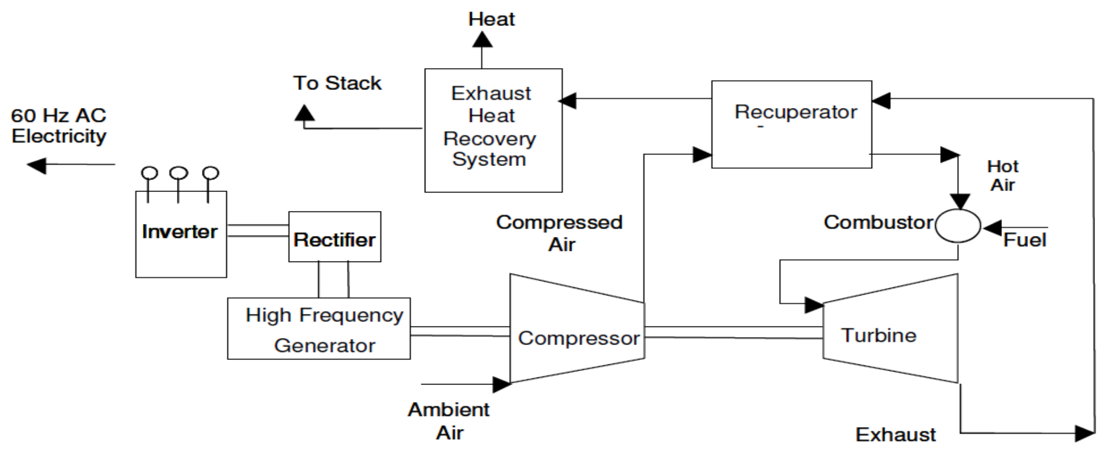


Figure 2- 13: **Micro Turbine-Based CHP System (Single-Shaft Design). Source: Energy and Environmental Analysis, Inc., 2003.**

2.8.3. Efficiency of CHP technology

Every CHP application includes the recovery of heat that would otherwise be wasted. In this way, CHP increases fuel-use efficiency. Two measures are commonly used to quantify the efficiency of a CHP system: total system efficiency and effective electric efficiency. It differs by technology and by size where larger systems of a given technology generally more efficient than smaller systems.

2.8.3.1. Total system efficiency

Total system efficiency is the measure used to compare the efficiency of a CHP system to that of conventional supplies (the combination of grid-supplied electricity and useful thermal energy produced in a conventional on-site boiler). If the objective is to compare CHP system energy efficiency to the efficiency of a site's conventional supplies, then the total system efficiency measure is likely the right choice.

2.8.3.2. Effective Electric Efficiency

CHP electrical efficiency is the term needed to compare CHP to conventional electricity production (i.e., grid-supplied electricity), where the effective electric efficiency metric is likely the right choice to do that which is how most electricity is produced. The assumptions that are taken in each methodology that are not appropriated in all cases. Consequently, the measure employed should be selected carefully and the results interpreted with caution.

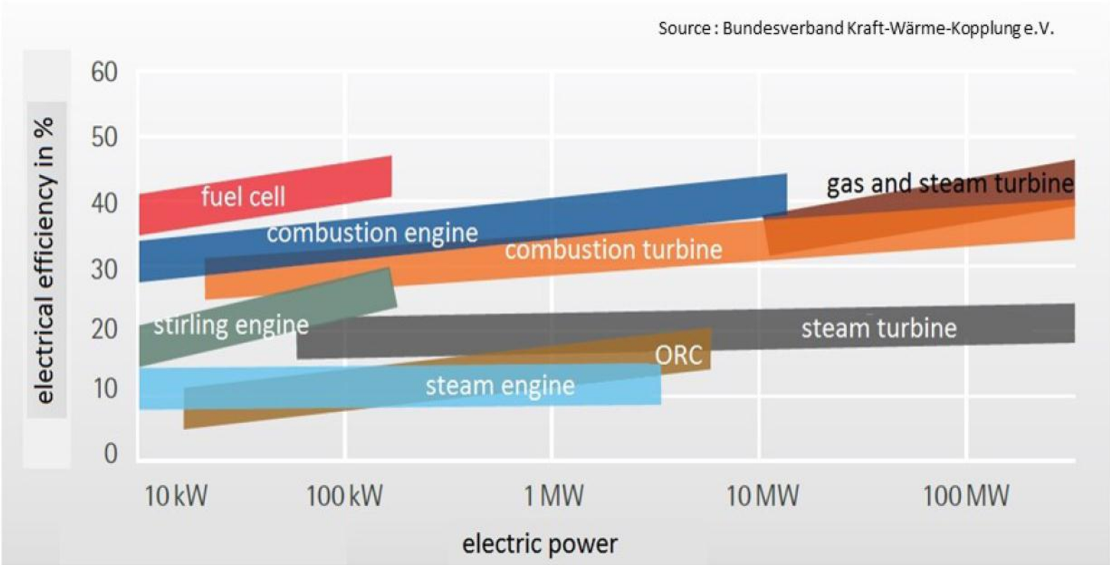


Figure 2- 14: **Electrical efficiency vs. electrical power for the main CHP prime movers. Source: BKWK**

SO, there is overlap in efficiency ranges among the five technology classes, but, in general, to get the highest electric efficiencies that are achieved by fuel cells, followed by large reciprocating engines, simple cycle gas turbines, micro turbines, and then steam turbines (Darrow, K., 2015). Converting additional heat into electricity by steam turbines with large gas turbines operating in combined cycle can achieve the highest electric efficiencies. Overall CHP efficiency which is dependent on the quality of the heat delivered, is One of the key characteristics of CHP, as the inefficiencies in electricity generation increase the amount of heat produced that can be utilized for thermal processes which effect the overall efficiency. Thus, the combined electric and thermal energy efficiency remains in a range of 65-80 percent (Darrow K., 2015).

Table 2. 6: Summary of CHP Technology Advantages and Disadvantages

CHP Technology	**Advantages**	**Disadvantages**	**Available Sizes**
Reciprocating Engine	It has a good load		1 kW to 10 MW

	following capability.	Its maintenance costs is high.	
Reciprocating Engine (Dual Fuel Pilot Ignition)	It can be overhauled on site with normal operators. It operates on low pressure gas. It has high power efficiency with a part-load operational flexibility. It is fast start-up. Its investment cost is low.	It is limited to lower temperature cogeneration applications. It must be cooled even if recovered heat is not used. High levels of low frequency noise with high air emissions	High speed (1,200 RPM) ≤4MW < 80 MW for Low speed (60-275 RPM
SteamTurbine	High overall efficiency – steam to power. It can be mated to boilers firing a variety of gaseous, liquid or solid fuels. Its ability to meet more than one site heat grade requirement. Long life and high reliability. Its power to heat ratio can be varied.	Its startup is slow. Its power to heat ratio is low. Requires a steam source.	50 kW to several hundred MWs
Gas Turbine	Its reliability is high. Its emission is low. Nocoolingrequired.	It requires a high pressure gas or in-house gas compressor. It ha poor efficiency at low loading. Its output falls as ambient temperature rises.	500 kW to 300 MW
Micro Turbine	It is small number of moving parts. Compact size and it has light weight. Its emissions is low. Nocoolingrequired.	It is cost is high. Relatively low mechanical efficiency. It is limited to lower temperature cogeneration applications.	30 kW to 250 kW with multiple unit packages up to 1,000 kW
Fuel Cells	Low emissions and low noise. High efficiency over load range. Modular design.	Its costs is high. Fuels require processing unless pure hydrogen is used. It has sensitive to fuel impurities.	5 kW to 2 MW

		low power density.	

Source: Catalog of CHP technologies. US Environmental Protection Agency, (2015).

Table 2. 7: Comparison of CHP Technology Sizing, Cost, and Performance Parameters

Technology	Recip. Engine	Steam Turbine	Gas Turbine	Micro turbine	Fuel Cell
Efficiency	27-41%	5-40+%2	24-36%	22-28%	30-63%
Overall CHP Efficiency	77-80%	near 80%	66-71%	63-70%	55-80%
Effective Electrical Efficiency	75-80%	75-77%	50-62%	49-57%	55-80%
Typical Capacity (MWE)	0.005-10	0.5-several hundred MW	0.5-300	0.03-1.0	200-2.8 commercial CHP
Typical Power to Heat Ratio	0.5-1.2	0.07-0.1	0.6-1.1	0.5-0.7	1-2
Part-Load	Ok	Ok	Poor	Ok	Good
CHP Installed Costs ($/kWe)	1,300-2,900	$670-1,100	1,200-3,300 (5-40 MW)	2,500-4,300	5,000-6,500
Non-Fuel O&M Costs ($/kWhe)	0.002 - 0.025	0.006 - 0.01	0.009 - 0.013	0.009 - 0.013	0.032 - 0.038
Availability	96 - 98%	72 - 99%	93 - 96%	98 - 99%	> 95%
Hours to Overhauls	30,000 - 60,000	> 50,000	25,000 - 50,000	40,000 - 80,000	32,000 - 64,000
Start-Up Time	10 secs	1 hr. - 1 day	10 min - 1 hr.	60 secs	3 hrs. - 2 days
Fuel Pressure (Psig)	1 – 75	n/a	100 - 500 (compressor)	50 - 140 (compressor)	0.5 - 45
Fuels	Biogas, LPG, sour gas, natural gas, waste gas, industrial manufactured gas.	All	Natural gas, gas, synthetic, landfill gas, and fuel oils.	Natural gas, liquid fuels, sour gas,	Hydrogen, propane, natural gas, methanol.

Uses for Thermal Output	Hot water, space heating, cooling, LP steam.	District heating, process steam, hot water, chilled water.	Heat, hot water, LP-HP steam.	Hot water, chiller, heating.	hot water, LP-HP steam
Power Density (kW/M^2)	35 – 50	> 100	20 – 500	5 – 70	5 – 20
NO_x (Lb/MMBtu) (Not Including SCR)	0.013 rich burn 3-way cat.0.17 lean burn	Gas 0.1-.2 Wood 0.2-.5Coal 0.3-1.2	0.036 - 0.05	0.015 - 0.036	0.0025 – 0.040
NO_x (Lb/MWh Total Output) (Not Including SCR)	0.06 rich burn 3-way cat.0.8 lean burn	Gas 0.4-0.8Wood 0.9-1.4 Coal 1.2-5.0.	0.52 - 1.31	0.14 - 0.49	0.011 - 0.016

Source: Catalog of CHP technologies. US Environmental Protection Agency, (2015).

The five technologies described in the table present 97 % of the CHP projects in place today and 99 % of the total installed CHP electric capacity in U.S.

Table 2. 8 Installed CHP Sites and Capacity by Prime Mover

Prime Mover	**Sites**	**Share of Sites**	**Capacity (MW)**	**Share of Capacity**
Reciprocating Engine	2,194	51.9%	2,288	2.7%
Gas Turbine*	667	15.8%	53,320	64.0%
Boiler/Steam Turbine	734	17.4%	26,741	32.1%
Microturbines	355	8.4%	78	0.1%
Fuel Cell	155	3.7%	84	0.1%
Other	121	2.9%	806	1.0%
Total	4,226	100.0%	83,317	100.0%

Source: U.S EPA Catalog of CHP Technologies, 2015

2.8.4. Reciprocating internal combustion engines technology characterization:

2.8.4.1. Basic processes

There are two types of reciprocating gas spark ignition engine designs that are used in generation power applications. They are the spark ignition Otto-cycle engine and the compression ignition Diesel-cycle engine.

The mechanical basics components of the spark engine and Diesel-cycle are the same. They use a cylindrical combustion chamber where a close-fitting piston travels the length of the cylinder. The piston links to a crankshaft that transforms the motion of the piston into the rotary motion of the crankshaft. Most engines have multiple cylinders to power a single unit of crankshaft. The main difference between the two cycles is the method of igniting the fuel. The Otto-cycle uses a spark plug to ignite the air fuel mixture introduced into the cylinder (Darrow K., et al., 2015).

Compression ignition engines (diesel) compress the air introduced into the cylinder to a high pressure, by raising its temperature to the auto-ignition temperature of the fuel that is injected at high pressure.

Reciprocating engines are also categorized by their original purpose of design, such as truck, automotive, industrial, marine and locomotive. Using automotive engine models is done by hundreds of small-scale stationary power, and chiller applications, CHP, irrigation, (Darrow K., et al., 2015). Due to its economies of scale of large production volumes, these are generally low-priced engines. Truck engines are designed for long life projects and having the cost benefit of production volume. A number of that engine is available as stationary engine. Engines are designed for durability and industrial use with a wide range of mechanical drive and electric power applications. In standby service, there are two cycle engines in stationary power applications. Nevertheless, most spark and diesel engines relevant to stationary power generation applications complete the power cycle in four strokes of the piston within the cylinder as shown in Figure 2-14.

1. Intake stroke: it introduces air (diesel) or air-fuel mixture spark ignition into the cylinder.

2. Compression stroke: it compresses air or an air-fuel mixture within the cylinder.

In diesel engine, the fuel is injected near the end of the compression stroke, and ignited in the cylinder by the elevated temperature of the compressed air.

In spark ignition, by an ignition source, the compressed air-fuel mixture is ignited.

3. Power stroke: it accelerates the piston by the expansion of the hot and high pressure combustion gases.

4. Exhaust stroke: expulsion of combustion products through the exhaust port from the cylinder.

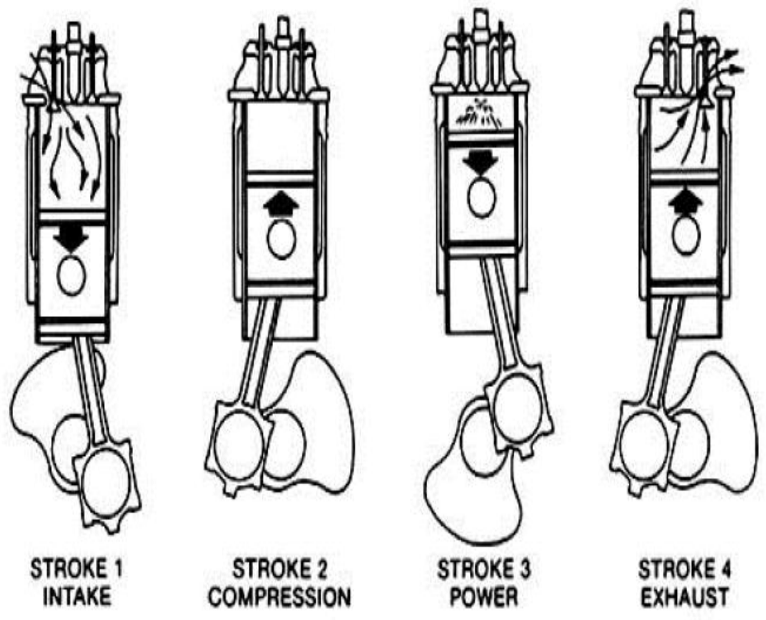


Figure 2- 15: 4-Stroke Reciprocating Engine Cycle source: U.S. DOE Combined Heat and Power Installation Database, data compiled through December 31, 2015

2.8.4.2. Components

2.8.4.2.1. Engine system natural gas spark ignition engines

The characteristics of the current natural gas engines for power generation has low first cost, proven reliability when properly maintained, fast start-up, significant heat recovery potential and excellent load-following characteristics,. Electric efficiency of natural gas engines ranges from (27 percent HHV) 30 percent LHV for small stoichiometric engine around (3 MW) (The exact ratio of air to fuel that is needed for complete combustion is called the stoichiometric ratio. the engine is called rich burn or lean burn) If there is less or more air than what is needed for complete combustion. Recovered Waste heat from the exhausted hot engine and from the engine cooling systems produce hot water or low-pressure steam for CHP applications. Hence, Overall CHP system efficiency (electricity and useful thermal energy) of up to 80 percent (HHV) can be obtained. Spark ignition engine uses spark plug, with a high-intensity spark of duration of time, to ignite a compressed fuel-air mixture into the cylinder.

In electric generation and CHP applications, natural gas is the predominant spark ignition engine fuel used but, also other gaseous and volatile liquid fuels can be used ranging from landfill gas to gasoline to propane, can be used with the proper fuel system, tuning engine and compression ratio.

American manufacturers began developing a large natural gas engine for the burgeoning gas transmission industry after the World War II. Smaller engine was developed (or converted from diesel blocks) for gathering the gas and other stationary applications due to development of the natural gas infrastructure. Natural gas engine for power generation application is primarily 4-stroke engines, available in various sizes up to about 18 MW (Darrow K., et al., 2015). Depending on the engines size, one of two ignition techniques ignites the natural gas:

• First is Open chamber: the spark plug tip is opened in the combustion chamber of the cylinder, igniting directly the compressed fuel-air mixture. Open chamber ignition is suitable to any engine operating that near the stoichiometric air/fuel ratio up to moderately lean mixtures (Stoichiometric ratio is the chemically correct ratio of fuel to air for complete combustion, i.e., there is no unused fuel or oxygen after combustion)

• Second is Pre-combustion chamber: a staged combustion process where the spark plug is housed in a small chamber mounted on the cylinder head. The cylinder is charged by a rich mixture of fuel and air, which upon ignition injects into the main combustion chamber in the cylinder as a high energy torch. This technique gives sufficient ignition energy to light off very lean fuel-air mixtures which used in large bore engines (Lean mixture is a mixture of fuel and air in which an excess of air is supplied in relation to the amount needed for complete combustion; similarly, a rich mixture is a mixture of fuel and air in which an excess of fuel is supplied in relation to the amount needed for complete combustion).

The natural gas engine which is the simplest operates by a natural aspiration of air and fuel into the cylinder (via a carburetor or other mixer) by the suction of the intake stroke. High performance natural gas engine is turbocharged to push more air into the cylinders. Natural gas spark ignition engine operates at the modest ratio of compression (compared with diesel engines) with the range of 9:1 to 12:1 depending on design of engine and turbocharging.

Using high energy ignition technology with very lean fuel-air mixtures can be burned in natural gas engine, with lowering peak temperature within the cylinders, and resulting in reduced NOx emissions. The lean burn approach in reciprocating engines is like to dry low-NOx combustors in gas turbines. All major natural gas engine manufacturers offer lean burn with low emission models and are involved in R&D to further improve their performance. Natural gas spark ignition engine efficiency is typically lower than diesel engine because of their lower compression ratios.

However, high, large performance lean burn engine efficiency can exceed those of diesel engine of the same size. Natural gas engine efficiency ranges from about 28 percent (LHV) for the small engine (= 1,000 rpm) is available for up to about 4 MW in size (Darrow K., et al., 2015). Low speed diesel engine (60 to 275 rpm) is available as large as 80 MW. Medium speed diesel engine (400 – 1000 rpm) is available for up to approximately 17 MW (Darrow K., et al., 2015). Typically, Diesel engine requires a compression ratio of 12:1 to 17:1 to heat the cylinder air to a temperature at which the injected fuel will ignite. The quality of fuel injection significantly affects the diesel engine operating characteristics, fuel efficiencies, and emissions.

Good fuel and Fine atomization dispersion by the injectors are important for ideal combustion, rapid ignition and emissions control. Manufacturers are moving increasingly toward controlled electronically, high pressure injection systems that provide more precise calibration of fuel delivery and accurate injection timing. Diesel Engine produces 5 to 20 times NOx (on a ppmv basis) of a lean burn natural gas engine, depending on the engine and fuel quality,

Diesel engine on marine engine usually emits up to 20 lbs NOx/MWh and presents on road engine emits less than 13 lbs NOx/MWh. New diesel engine will achieve rates of approximately 0.65 lb NOx/MWh. Diesel engine also produces assorted heavy hydrocarbons and particulate the emissions. However, diesel engine produces significantly less carbon mono oxide than lean burn gas engine. The NOx emission from diesel burning heavy oil is typically 25 to 30 percent which higher than diesel using distillate oil. Common NOx control technique includes delayed fuel injection, water injection, exhaust gas recirculation, inlet air cooling, intake air humidification, fuel-water emulsification, and compression ratio and/or turbocharger modifications.

In addition to that, an increasing number of larger diesel engines are equipped with oxidation catalyst systems and selective catalytic reduction for post combustion emissions reduction. Generally, High speed diesel engine requires high quality fuel oil and good combustion properties. Ultra-low Sulphur diesel with Sulphur content of less than 0.15 ppm is now needed for the new Tier 4 diesel engine to decrease Sulphur emission. High speed diesel engine is not convenient for burning oil heavier than distillate. Heavy fuel oil requires over time for combustion and the combination of high speed and contaminants in lower quality heavy oils cause too much wear in high speed diesel engines. Many medium and low speed diesel designs burn heavier oils involving low grade residual oils or Bunker C oils.

2.8.4.2.2. Dual fuel engines

Predominantly, they are fuelled by natural gas with a small percentage of diesel oil added. Mainly, there are two configurations to introduce the gaseous fuel in a dual fuel engines. These engines can be aimed built or conversions of diesel engines. Such engines can be turned into 100 percent diesel operation. Dual fuel engine provides a multi-use functionality.

Predominantly, Operation of cleaner and cheaper natural gas burning allows the engine to be used in CHP applications and peak shaving, while operation on 100 percent diesel allows the engine to meet also the onsite requirements of fuel of emergency generators. The dual function adds advantage in application that has specific emergency generator requirement such as in hospital or in public buildings. Mainly, there are three configurations to introduce the gaseous and pilot diesel fuel:

1) High pressure injection after the intake air has been compressed by the piston

2) Low pressure injection with the intake air, and

3) Micro pilot re-chambers introduction of the diesel fuel.

New dual-fuel engine is offered in oil and gas production market for reducing operating costs. Dual-fuel retrofit of existing diesel engine is also offered as a means for reducing both operating cost and emission for extending the hours of use for limited duty engine such as emergency and peaking applications. Widely, Dual fuel is not used for CHP applications.

2.8.4.3. Heat Recovery

On-site power generation applications, usually, the economics of engines depend on the effective use of the thermal energy which is contained in the exhaust gas and cooling systems, which represents generally 60 to 70 percent of the fuel energy. Most of the wasted heat is available in the engine exhaust and jacket coolant, while smaller amounts can be recovered from the turbocharger's intercooler and after cooler (if so equipped) and the lube oil cooler by 45 to 55 percent. Generally, this feature is less critical in commercial/institutional applications, where it is more common to have hot water thermal loads. If required, Steam can be produced from the exhaust heat (maximum pressure of 400 psig), but if no hot water is needed, the amount of recovered heat from the engine is decreased and total CHP system efficiency declines accordingly. Heat in the engine jacket coolant accounts up to 30 percent of the energy input and is capable of producing 190 to 230 °F hot water (Darrow K., et al., 2015). Some engines, such as those with high pressure or ebullient cooling systems which can operate with water jacket temperatures over 265°F. Engine exhaust heat represents 30 to 50 percent of the available wasted heat. Exhaust temperatures for the example systems range from 720 to 1000°F (Darrow K., et al., 2015). By recovering the wasted heat in the cooling systems and exhaust, around 80 percent of the fuel's energy can effectively be utilized for producing both power and useful thermal energy.

Closed loop cooling system: the most common method of recovering engine heat is the closed loop cooling system as in Figure 2-16. That system is designed to cool the engine by forced circulation of a coolant within engine passages and an external heat exchanger (Darrow K., et al., 2015).

An excess heat exchangers transfer engine heat for cooling a tower or a radiator when there is an excess heat is generated. The system of closed loop water cooling can work at coolant temperature which ranges from 190 to 250°F. Depending on the engine and CHP system's requirements, the lube oil cooling and turbocharger after-cooling may be either separated or part of the jacket cooling system.

Ebullient Cooling Systems: Ebullient cooling system cools the engine by natural circulation of a boiling coolant within the engine. Typically, this type of cooling system is used in conjunction with exhausted heat recovery for production of low pressure steam.

Cooling water is introduced at the bottom of the engine where the transferred heat begins goes to boil the coolant generating two phase flow. The formation of bubbles lowers the density of the coolant, leading to a natural circulation to the top of the engine. At the engine outlet, the coolant is kept at saturated steam conditions and usually is limited to 250°F and a maximum of 15 psig. Below the outlet temperature, also Inlet cooling water is near saturation conditions and is generally 2 to 3°F (Darrow K., et al., 2015). The uniform temperature throughout the coolant circuit extends engine life and contributes for improving combustion efficiencies.

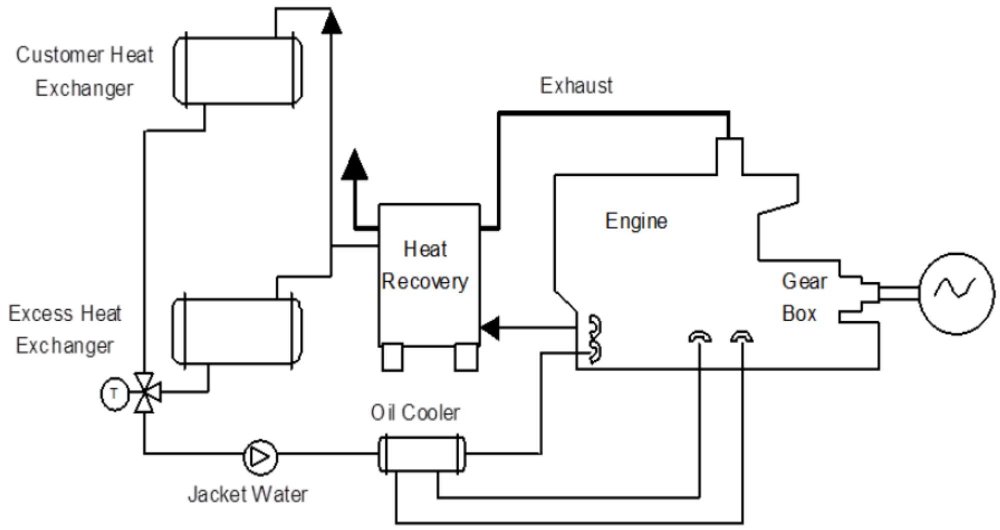


Figure 2- 16: **Closed-Loop Heat Recovery System (Darrow K., et al., 2015).**

Exhaust Heat Recovery: typically, Exhaust heat is used for generating hot water of up to about 230°F or steam up to 400 psig. Only a part of the exhaust heat can be recovered as exhaust gas temperature is generally kept above temperature thresholds for preventing the corrosive effects of condensation inside the exhaust piping. For this reason, mostly heat recovery unit is designed for a 250 to 350°F exhaust outlet temperature. The Exhaust heat recovery can be independent of the engine cooling system or connected with it. For example, hot water from the engine cooling can be used to feed water or feed water preheats to the exhaust recovery unit. In a typical district heating system, lube oil cooling, jacket cooling, and exhaust gas heat recovery and single stage after cooling are all integrated for steam production (Darrow K., et al., 2015).

2.8.4.4. Performance Characteristics

Summarization of the performance characteristics for typical commercially natural gas spark ignition engine CHP systems available over a 100 kW to 9 MW size range in Table 2-9. The majority of the market applications for engine-driven CHP are covered in this size range. The rate of heats and the presented efficiencies in the table were taken from manufacturers' specifications and industry publications. The available thermal energy mentioned was taken directly from vendor specifications or, if it was not provided, it was calculated from published engine data. Estimated CHP thermal recovery is based on producing hot water for processing or for space heating required. Depending on the intended load service, most reciprocating engine manufacturers typically assign three power ratings to engines (Darrow K., 2015):

- Standby: cycling load or continuous full for a relatively short duration which is usually less than 100 hours
- (Maximum power output rating).
- Prime: an unlimited time of continuous operation (except for normal maintenance shutdowns), but with regularly variations in load – 80 to 85 percent of the standby rating.
- Base load: continuous full-load operation for an unlimited time (except for normal maintenance shutdowns) – 70 to 75 percent of the standby rating.

Table 2. 9: The ratings are for base load operation. Gas Spark Ignition Engine CHP - Typical Performance Parameters (Darrow K., 2015).

Cost & Performance Characteristics	**System 1**	**System 2**	**System 3**	**System 4**	**System 5**
Base load Electric Capacity (kW)	100	633	1,121	3,326	9,341

Total Installed Cost in 2013 ($/kW) 2014	$2,900	$2,837	$2,366	$1,801 $1,300	$1,433
Electrical Heat Rate (Btu/kWh), HHV16	12,637	9,896	9,264	8,454	8,207
Electrical Efficiency (%), HHV	27.0%	34.5%	36.8%	40.4%	41.6%
Engine Speed (rpm)	2,500 17	1,800	1,800	1,500 18	720
Fuel Input (MMBtu/hr.), HHV	1.26	6.26	10.38	28.12	76.66
Required Fuel Gas Pressure (psig)	0.4-1.0	> 1.16	> 1.74	> 1.74	75
CHP Characteristics					
Exhaust Flow (1000 lb/hr.)	1.2	7.89	13.68	40.17	120
Exhaust Temperature (Fahrenheit)	1,200	941	797	721	663
Heat Recovered from Exhaust (MMBtu/hr.)	0.21	1.48	2	5.03	10
Heat Recovered from Cooling Jacket (MMBtu/hr.)	0.46	0.72	1.29	1.63	4.27
Heat Recovered from Lube System (MMBtu/hr.)	Incl.	0.27	0.44	1.12	5.0
Heat Recovered from Intercooler (MMBtu/hr.)	n/a	0.31	0.59	2.89	7.54
Total Heat Recovered (MMBtu/hr.)	0.67	2.78	4.32	10.67	26.81
Total Heat Recovered (kW)	196	815	1,266	3,126	7857

Source: Compiled by ICF from vendor supplied data.

2.8.4.5. Effects of Ambient Conditions on Performance

Reciprocating gas spark ignition engine is generally rated at ISO conditions of 77 °F and 0.987 at atmospheres (1 bar) pressure. Reciprocating engine performance is like gas turbines (Gas turbine is rated at 59 °F.), measured for both output and efficiency, and degrades as ambient temperature or site elevation increases. While the effect on gas turbines can be considerable, it is less so on engines. Efficiency of Reciprocating engine and its power are decreased by approximately 4 percent per 1,000 feet of altitude above 1,000 feet, and around 1 percent for every 10°F above 77°F.

2.8.4.6. Capital Costs

The basic generator package consists of the engine that is directly connected to a generator without a gearbox. In countries where 60 Hz power is required, the genset operates at multiples of 60 such as typically 1800 rpm for smaller engines, and for the large engines 900 or 720 or 514 rpm (Darrow K., et al., 2015). In areas where 50 Hz power is the available such as Europe and Japan, the engine runs at speed that is multiples of 50 – typically for the small engines is 1500 rpm. In Table 2-10, System 4 is based on a German design, and it operates at 1,500 rpm and produces 60 Hz power through a gearbox (Darrow K., 2015). The smaller engine is skid mounted with fuel system, a basic control system, starting system, fan, and radiator. Some smaller packages come with integrated heat recovery system, an enclosure, and basic electric paralleling equipment.

The cost of the basic engine package in addition to the costs for added systems needed for a certain application comprise the total equipment cost. The total plant cost consists of the total equipment costs plus the installation labour and materials even with including site work, project management (including licensing, insurance, engineering, commissioning and start up), and financial carrying costs during the 4 to 18-month(one and half year) construction period, and all engines are in low NO_x configuration.

A stoichiometric (rich burn) engine in System 1, uses a three ways catalyst for reducing emissions to their final level. Table 2.10 provides estimated cost for combined heat and power applications based on a single unit engine. However, the multi megawatt size engines are capable of producing low-pressure steam, The CHP system is assumed to produce hot water. The heat recovery equipment consists of the exhaust economizer that gives heat from the exhaust system, process heat exchanger for extracting heat from the engine jacket coolant, control system, circulation pump, and piping. These estimated cost include interconnection and paralleling. The costs packages are intended to be related to a generic representation of popular engines in each size category.

The interconnection/electrical cost reflects the costs of paralleling a synchronous generator for the larger system. System of 100 kW uses an inverter based generator that has been pre-certified to be interconnected in most areas.

Labour/materials represent the labour cost for the mechanical, civil, and electrical work as well as materials such as piping, ductwork, and wiring. The Project and the construction management also included general contractor mark-up and bonding, and performance guarantees. Contingency is assumed to be 5 percent of the total equipment costs in all cases. Cost estimates for multiple unit construction have lower unit costs than single unit installations.

2.8.4.7. Maintenance

Maintenance costs differs with type, speed, size and number of cylinders of an engine. Typically, these costs include:

- Maintenance labour,
- Engine parts and materials such as air filters, electronic components, gaskets, oil filters, valves, spark plugs, piston rings, etc. and consumables such as oil,
- Minor and major overhauls. Maintenance can either be done by in-house personnel or contracted out to manufacturers, dealers under service contracts, or distributors.

Full maintenance contracts which is covering all recommended service, generally cost between 1 to 2.5 cents/kWh depending on engine size and speed and service (Darrow, K., et al., 2015). Now, many service contracts have remote monitoring of engine performance costs and conditions in addition allowing for predictive maintenance.

Typically, Service contracts rate is all-inclusive, including the travel time of the technicians on service calls. Recommended service is involved in the routine short interval inspections/adjustments and periodic replacement of engine oil and filters, spark plugs, and coolant, (typically 500 to 2,000 hours) (Darrow K., et al., 2015). An oil analysis is part of most preventative maintenance programs for monitoring engine wear. Generally, a top-end overhaul is recommended between 8,000 and 30,000 hours of operation that includes a cylinder head and turbocharger rebuild. A major overhauls are performed after 30,000 to 72,000 hours of operation and involves piston/liner replacement, bearings, crankshaft inspection, and seals (Darrow K., et al., 2015).

Maintenance costs presented in Table 2-10 are based on engine manufacturer estimates for service contracts consisting of scheduled overhauls and routine inspections of the engine generator set. Costs that are based on 8,000 annual operating hours expressed in terms of annual electricity generation (Darrow K., et al., 2015).

Engine maintenance can be divided into fixed components that need to be regardless performed on a recurring basis of the engine run time and variable components that depend on the hours of operation. Base load operation, the vendors quoted all O&M costs on a variable basis for a system.

Table 2. 10: Estimated Capital Cost for Typical Gas Engine Generators in Grid Interconnected CHP Applications.

Capital Cost, $/kW	**1**	**2**	**3**	**4**	**5**
Nominal Capacity (kW)	100	633	1121	3326	9341
Equipment (Costs in 2013 ($/kW)					
Gen Set Package	$1,400	$400	$$375	$350	$575
Heat Recovery	$250	$500	$500	$500	$175
Interconnect/Electrical	$250	$140	$100	$60	$25
Exhaust Gas Treatment		$750	$500	$230	$150
Total Equipment	$1,900	$1,790	$1,475	$1,140	$925
Labour/Materials	$500	$448	$369	$285	$231
Total Process Capital	$2,400	$2,238	$1,844	$1,425	$1,156
Project and Construction Management	$125	$269	$221	$171	$139
Engineering and Fees	$250	$200	$175	$70	$30
Project Contingency	$95	$90	$74	$57	$46
Project Financing	$30	$42	$52	$78	$62
Total Plant Cost ($/kW)	$2,900	$2,837	$2,366	$1,801 (2013)	$1,433

				$1,300 (2014)	
Typical Natural Gas Engine Maintenance Costs ($2013/kWh)					
Service Contract	$0.023-$0.025	$0.020	$0.018	$0.015	$0.0075
Consumables included	Included	$0.001	$0.001	$0.001	0.001
Total O&M Costs, 2013	$/kWh $0.023 - $0.025	$0.021	$0.019	$0.016(2013) $0.002 (2014) (Olson A., et al., 2014)	0.0085

Source: Compiled by ICF from vendor supplied data.

2.9. CHP Potential in Algeria

97% of Algerian electricity is produced from natural gas, mostly with low efficiency simple cycle gas turbines. Algerian reserves are rapidly depleting and the need for efficiency arose (Michaut, S., 2013).

In this framework, developing CHP solutions with 45% electrical efficiency and up to 90% total efficiency is meaningful, and a deeper market analysis is needed to determine where and how to implement this technology.

2.10. Climate Change Legislation in Algeria

Algeria's environmental issues, connected with its significant reliance on fossil fuels, which account about 99% of its electricity generation, has led the government to encourage investments in both climate change adaptation and mitigation measures, one of the only North African countries explicitly to articulate strategies for comprehensive national adaptation and climate change mitigation. These strategies largely focus on 3 areas (Kingsmill N., et al, 2015):

(i) Implementation of plans for sustainable socio-economic development,

(ii) Building and integrating new and strengthening institutions and human capacity, and

(iii) Mitigation GHG emissions via energy diversification and reforestation efforts. Although most policy objectives are codified in law, the laws generally do not outline specific policy prescriptions.

Rather, they direct or recommend that the details be laid out in regulation. While climate change adaptation and mitigation measures frequently require interministerial collaboration, most of the legislation pertaining to climate change mitigation and adaptation are under the broad authority of four ministries:

- Land and Environment Management,
- Energy and Mines,
- Water Resources,
- Agriculture and Rural Development.

There are also many specialist agencies and centers that were existed to specifically address the challenges related with climate change, particularly in the context of sustainable development. These include: the National Observatory for Environment and Sustainable Development (NOESD), the National Waste Management Agency (NWMA), National Centre for the Development of Biological Resources (NCDBR), the National Centre for Cleaner Production Technologies (NCPT), the National Agency for Climate Change (NACC), the Inter-Sectorial Council of Energy Management (ICEM), and the National Agency for the Promotion and Rational Use of Energy (NAPRUE) (Kingsmill, N., et al, 2015). Since 1994, Algeria has been home to a Global Atmosphere Watch (GAW) monitoring program, in co-ordination with the World Meteorological Organization (WMO) with funding support from the World Bank, at Tamanrasset and Assekrem, in the Central Sahara. The remote location of these sites enables successful monitoring of GHGs, aerosols, ozone, carbon monoxide, and radiation (Kingsmill N., et al, 2015).

According to the guidelines that are done by the Intergovernmental Panel for Climate Change (IPCC), Algeria has published and conducted two national GHG inventories and absorptions: the first was in 1996, the results of which are explained in the First National Communication, and the second was in 2000, the results of which are explained in the Second National Communication, of November 2010 (Kingsmill N., et al, 2015). In 2005, the National Agency of Climate Change is charged for obtaining more periodic inventories of GHG emissions. Several National Action Plans support the goal development of sustainable economic.

Algeria published its first National Plan of Action for the Sustainable and Environment Development (PNAE-DD) in 2002, that was financed with a grant from the European Commission and the Swiss Agency for Development and Corporation

(SDC) and further assisted by the World Bank, German Technical Cooperation Agency (GTZ), and the Mediterranean Environment Technical Assistance Program (METAP) (Kingsmill, N., et al, 2015).

This plan highlighted Algeria's previous lack of integration in policies, program, enforcement action and institutions related to climate change and the environment, proposing that, moving forward, Algeria mainstream its aims for environmental protection with the agenda of a sustainable development.

Algeria adopted a National Plan of Action and Adaptation to Climate Change (PNA-ACC) in 2003, which was updated in 2013(Kingsmill N., et al, 2015). This plan outlines both climate change mitigation and adaptation policy measures with including the promotion of: renewable energy technologies, industrial emission reductions, carbon sequestration, reforestation and water system innovation.

Frequently Algeria has a number of supranational actors regarding regional mitigation and adaptation measures, the Arab League, the Arab Maghreb Union and including the African Union; however, none of the declarations or initiatives agreed upon by these organizations are legally binding.

2.11. Algeria: Executive Used Portfolio Available For Such Project:

Name of Policy: Regulatory Order fixing the guaranteed purchase price and the conditions of their application for electricity generated from facilities using photovoltaic segment.

Date: 2 February 2014

Summary: Established a variable 20 year Solar PV feed-in-tariff (FIT) for ground-mounted solar installations greater than 1MW, with reviewing the energy program, Fixed the FIT for 1MW to 5MW installations at 15.94 DZD per kWh for the first 5 years and between 20.08 DZD per kWh to 11.80 DZD per kWh for the following 15 years. For installations larger than 5MW, the FIT is fixed at 12.75 DZD per KWh for the first 5 years and between 12.75 DZD per kWh and 9.44 per kWh for the final 15 years (Kingsmill N., et al., 2015). Paying the FIT for a limited number of hours per year, following which electricity is sold at a conventional price.

2.12. The Benefits of Installing CHP in WWTPs

Regardless of sector or application, CHP integrated system benefits include:

- Efficiency benefits: CHP requires less fuel than the conventional case of separating heat and power generation for producing a given energy output. CHP also avoids transmission and distribution losses that takes place when electricity travels through power lines from central generating units (Bastian R., et al, 2011). Which represented in:
- Reliability advantages: CHP can offer high-quality electricity and useful thermal energy to a site regardless of what may happen on the power grid, reducing the impact of outages and improving power quality for sensitive equipment.
- Environmental benefits: Because more less fuel is burned for producing each unit of energy output, CHP decreases emissions of greenhouse gases and other air pollutants (Bastian, R., et al, 2011).
- Economic benefits: CHP can save facilities considerable money on their energy bills because of its high efficiency.

So, WWTPs can experience efficiency, environmental, reliability, and economic benefits with CHP technology. In general, the primary drivers and advantages reported by the WWTPs, which specifically include the following:

- Energy cost savings,
- Energy/sustainability plans and emissions reductions,
- Enhanced reliability,
- Increasing biogas production,
- Enhancing bio solid management and,
- Utility load shedding.

2.13. The Case Study for reframing the Techno Economic Analysis module.

The Orange Water and Sewer Authority (OWASA) is a public and non-profit agency that provides wastewater, water, and re-engine alleged water services to the Carrboro-Chapel Hill community in North Carolina. OWASA has and operates the Mason Farm Wastewater Treatment Plant with a small to medium facilities that has a permitted peak month capacity of 14.5 mgd and currently treats average of 7.5 mgd (Karen Durden et al, 2013).Thickened fermented primary sludge and Thickened waste activated sludge are pumped into digesters where they undergo through temperature phased an-aerobic digestion (TPAD) for producing biogas.

And for implementing internal combustion reciprocating engine CHP with nominal capacity 700 Kw, the Researchers got results and compared them of using alternative metrics for doing a techno economic feasibility.

Key assumptions used in the analysis include (Karen Durden et al, 2013).

- The CHP project constructiona cost is $4,000,000 and an engineering cost of $500,000.
- Nominal discount rate based on the White House's Office of Management and Budget guideline for The financial analyses 3.5% using economic evaluation studies: for 20 year investments.

Using the financial data from the OWASA case study researchers calculated the metrics that are used for doing the techno economic analysis that will be described in the next chapter and compared all of them to the payback period method. Alternative one compares current operation (energy from the conventional gris sysstem) to the CHP project, with assuming constant sludge production over the planning horizon, but alternative two compares the current operation to an escalated CHP project, with assumption of 2% annual increase in sludge production and escalation of power costs at 1% greater than inflation.

For each metric, the values are calculated and shown and recommended with a corresponding to project action. Table down shows the results of this comparison and what the decision outcomes would likely be.

Table 2. 11: Financial Results for Alternative Metrics

Item	Alternative 1 – Constant	Alternative 2 – Escalated
Capital Cost	$4,200,000	$4,200,000
Annual Operating Savings	$334,257	$367,264
Payback Period	12.6 years	11.4 years
Project Action	Dependent on utility's requirements for payback period, this value can result in the project being rejected	Dependent on utility's requirements for payback period, this value can result in the project being rejected
Present Value of Savings (or Benefits)	$9,681,618	$9,929,725
Present Value of Costs	$9,299,692	$9,162,267
Net Present Value	$381,925	$767,457
Project Action	NPV > 0, so consider accepting CHP project	NPV > 0, so consider accepting CHP project
BCR	1.041	1.084
Project Action	BCR >1, so consider accepting CHP project	BCR >1, so consider accepting CHP project
Discount Rate, i	3.5%	3.5%
IRR	4.5%	5.5%
Project Action	IRR > i, so consider accepting CHP project	IRR > i, so consider accepting CHP project
EUAB	$681,209	$698,666
EUAC	$654,336	$644,667
NUV	$26,873	$53,999
Project Action	NUV > 0, so consider accepting CHP project	NUV > 0, so consider accepting CHP project

Source: Reframing the Economics of Combined Heat and Power Projects. (Karen Durden et al, 2013).

The payback period is approximately 12 years as shown in Table for both the CHP alternatives. Depending on the utility and PBP method, CHP projects may be viewed as marginal investments based on a 12 year payback period and might be rejected. However, all the other metrics suitable for long-term projects life exceed the threshold values for recommending moving the CHP project forward.

Some other utilities of this methods that have already had success reframing the economics of its CHP application and moving projects forward using alternative financial metrics that consider the full life cycle of the investment. By focusing on long run economic criteria better than simple payback, the argument for CHP is mostly always more compelling.

The City of St. Petersburg used net present value and operational savings to rationalize construction of CHP. The CHP project based on a 20 years present worth cost of $30 million which is less than the baseline $102 million. Besides that, the project saves approximately $3 million per year from operating costs. In Massachusetts, estimated that save approximately $300,000 annually would be saved by its CHP project in electricity and bio solids management costs (Karen Durden et al, 2013).

2.14. Summary

The Strong environmentally and economically benefits from operating CHP in WWTPs and suggests that CHP is a proven method of utilizing digester gas to both produce and conserve energy; which makes CHP is a proven technology in WWTPs providing energy savings, reduced emissions, and opportunities for resiliency and new business in Algeria. In order to get as much as benefits of CHP system, it is supposed to have the right technology by sizing the technology for the proposed project. The type of equipment that drives the overall system (i.e. the prime mover) typically identifies the CHP system and its financial data

CHAPTER 3. METHODOLOGY

Outlines

1. Introduction.
2. The energy content of biogas in WWTP El Karma.
3. CHP energy output.
4. Conventional Case Energy Consumption in WWTP El Karma (Grid Electricity + On-Site Boiler).
5. Techno economic analysis module.
6. Using metrics to support decision. Energy cost (fuel and electricity grid).
7. Risk assessment.

1.5. Introduction

The following section contains equations used to calculate the energy demand in WWTTP El Karma and a brief description of the decision-making tool used for a preliminary design analysis to assess the feasibility of cogeneration in WWTP of El Karma. The techno-economic performance of the CHP is compared to the current situation of the WWTP El Karma (electricity from the grid and heat from on-site boiler).

The module tool uses technical and economic inputs from biogas plant as well as CHP. The most important parameters used in the economic appraisal of the CHP technology are as follows (Nkoi, B., et al., 2015): Payback Period (PBP), Net Present Value (NPV), Internal Rate of Return (IRR), and Profitability Index (PI).

3.1. Biogas production at WWTP El Karma

By knowing the amount of biogas produced from the digester that is available per month which is estimated to be 3888000m^3/year and the LHV of the biogas per cubic meter at El Karma, the energy quantity can be calculated for CHP technology to be used for the sizing of CHP plant.

3.1.1. Calculation of primary energy used in CHP

Total fuel energy input (Q_{FUEL}): The heating value of the total fuel input, Total fuel input is the sum of all the fuel used by the CHP system. The total fuel energy input is often determined by multiplying the quantity of fuel consumed by the heating value of the fuel (U.S. EPA).

Total energy input** = **heating value of biogas** × **annually amount of biogas **(1)**

3.1.2. Biogas contents and (LHV) in WWTP El Karma

In WWTP El Karma, the analyses carried out by means of chromatography gave the following results on the biogas composition:

Table 3. 1: Biogas content in WWTP El Karma

Components	Components Proportion (%)
CH_4	**65%**
CO_2	**30%**
H_2S, H_2O, CO	**5%**

The table below shows the low heating value of biogas at different percentage of methane. So, the lower calorific value (LHV) of the biogas produced in WWTP El Karma is 6.53 kWh /m^3

Table 3. 2: Dry Biogas [CH4 and CO2] at 32 F & 1 ATM % (Ludington, D., DLtech, P., & NY, I. I., 2006)

% CH_4 by volume	g mol wt	CH_4 Percent by weight	Density lbs d.g.*/ft^3	Density ft^3/lb d.g.	LHV Btu/ft^3
40%	32.8	19.6%	0.0916	10.92	385
42%	32.3	20.9%	0.0900	11.11	405
44%	31.7	22.3%	0.0885	11.30	424
46%	31.1	23.7%	0.0869	11.50	443
48%	30.6	25.2%	0.0854	11.71	463
50%	30.0	26.7%	0.0838	11.93	482
52%	29.5	28.3%	0.0822	12.16	501
54%	28.9	30.0%	0.0807	12.39	520
56%	28.4	31.7%	0.0791	12.64	540
58%	27.8	33.5%	0.0776	12.89	559
60%	27.2	35.4%	0.0760	13.16	578
62%	26.7	37.3%	0.0744	13.43	598
64%	26.1	39.3%	0.0729	13.72	617
66%	25.6	41.4%	0.0713	14.02	636
68%	25.0	43.7%	0.0698	14.34	655
70%	24.4	46.0%	0.0682	14.66	675

* dry gas

3.2. CHP Energy Output

CHP increases fuel-use efficiency. Total CHP systems efficiencies range from 75 to 90 %. The Electricity and thermal generation outputs can be calculated using the equations 3.2 and 3.3 (U.S. EPA):

Annual electricity output = electrical efficiency x annual fuel input (kW)   (3.2)

Annual thermal output = thermal efficiency x annual fuel input (kWh)   (3.3)

Energy consumption data must always be measured and requested before assessing the feasibility study. In principle, two situations can be distinguished:

- **Plant with available historical annual consumption data:**

The energy consumption in existing plants has usually been established over a number of years, and plant operators can see this information in their annual energy statement (monthly bill). Quarter hourly electricity demand data can be obtained from the building's electricity supplier, it is the case used in this study.

- **New plant where no energy consumption data is available:**

Users must estimate their annual consumption since they have no annual data at their disposal, and normally in the new plant, energy saving measures are already included. Plant simulation software can be a valuable tool in establishing the exact heat demand. Through monitoring, the electricity demands are usually easier to be determined.

3.3. Conventional Case Energy Consumption in WWTP El Karma (Grid Electricity + On-Site Boiler)

For implementing an economic evaluation of a CHP project, the energy demand in terms of electrical power and heat consumption on site must be obtained. In selecting CHP plant, depending on power to heat ratio, decision must be taken whether to match electricity demand and have deficit of heat or match heat demand and have deficit of electricity. The energy demand (consumption) of the plant is reported for a given period of time which is a year while records are kept on daily and monthly bases. Also, the number of hours of the operation must be known. Energy generation, consumption and biogas production vary with seasons of the year (winter, spring, autumn, summer) and with daily ambient temperature.

3.3.1. Consumption of heat in WWTP El Karma

The consumption of heat in WWTP EL Karma is done by estimating the amount of biogas used in WWTP El Karma for heating the boilers to be used in the anaerobic digester to maintain its temperature at 37ºC.

The boilers manufacturer is Loos International, model UT-L 14, with the following characteristics:

Table 3. 3: characteristic of the boilers in WWTP El Karma

Maximum pressure:	9 bars
Test pressure:	9.6 bar
Maximum temperature:	110 °C
Number of boilers:	3
Total volume:	1690 l
Total Thermal power:	1800 KW
Yield (Efficiency):	80%

The biogas burnt in the boiler is calculated as follows:

$$\textit{Real power (Kw)} = \textit{Thermal power x Efficiency} \qquad (3.4)$$

3.3.2. Electricity consumption in WWTP El Karma

In WWTP El Karma, for all equipment, the hourly distribution were recorded from hourly counters of the dashboard plant. The last step of the recording permits the elaboration of a database where the daily and the monthly uptimes and their hourly distribution are recorded. These two steps allowed the assessment of the monthly electricity consumption of the electrical equipment.

Moreover, the calculation of their electricity consumption and their cost was carried out using the hourly distribution of the electricity consumed according to the hourly electricity price plan used in industrial sector in Algeria. During the WWTP operation, the electricity consumed from the grid at a national level and delivered by the interconnected national distribution network using the electricity tariff of 0.035$/kWh.

3.4. Techno Economic Analysis Module

The water environment research foundation (WERF) Barriers to Biogas Use for Renewable Energy project found that utilities used to use the basic payback-period method to assess the feasibility of a CHP project, which is calculating how long the project takes to recover its costs. Nevertheless, this method actually ignores the long-term cash flow and the time value of money which is invested. When a reasonable long term project (timeframe) could be 10, 20, or as many as 30 years that most assets multi-decade life, this simplistic calculations produce incomplete information that can cause flawed decision and leading to misunderstanding the benefits and financial analysis output.

In an environment of competing demands with limited capital such as WWTPs, this can make a difference in a biogas project (CHP) through approving other metrics that consider the full-life cycle of a potential project and create a better vision of the long term value. And to illustrate how different financial metrics can affect decision makers' to evaluate the financial case for getting energy at WWTP facility using several methods. The financial outcome of implementing CHP at the WWTP facility El Karma that currently generates biogas, using the payback method as well as the following alternative methods:

- Net Present Value (NPV).
- Benefit Cost Ratio (profitability index) (PI).
- Internal Rate of Return (IRR).

3.4.1. Net present value

Net present value is the difference between the present worth of all expenses and the present worth of all revenues during the life cycle of a CHP operation (Nkoi, B., et al., 2015) (Budzianowski, W. M., and Dominika A., 20105). It includes savings, and is the present worth of the total net cash flow of the CHP investment.

$$\boldsymbol{NPV = -F_0 + \sum_{t=0}^{N} \left(\frac{Ft}{(1+dt)^{\ t}}\right)} \textit{(3.5)}$$

Where $\mathbf{d_t}$ = the current interest rate or market discount rate during the period t, and when it is considered constant d_t= d.

N = (the life of the CHP plant). Time period in years is usually used.

F_t = the annual net cash flow in year t (revenue + savings – expenses).

The term "net cash flow" could be negative, that indicates loss in year t.

F_0= the present worth of the investment (at time = 0), and it is negative. It is equal to the capital cost (Nkoi, B., et al., 2015).

There are three possible solutions:

- If NPV > 0; → return on investment (RoI) > d; so, economically viable investment, given condition (N, d)
- If NPV = 0; → return on investment (RoI) = d; so, economically viable investment, given condition (N, d)
- If NPV < 0; → return on investment (RoI) < d; so, investment is not economically viable under the given specification (N, d).

3.4.2. Payback- period

Payback period is the time of recovering the initial cash outflow of the investment. Or in which it is expected to be paid back from the cash inflows that gained by the investment. It is one of the simplest investment techniques.

The formula for calculating payback period of a project depends on whether the cash flow per period from the project is even or uneven. In case they are even, the equation of calculating the payback period is given by (3.6).

$$\boldsymbol{PBP = \frac{Initial\ Investment}{Cash\ Inflow\ per\ Period}} \qquad \textbf{(3.6)}$$

3.4.3. Algorithm for computing the net present value of CHP

- Initial investment cash flow (F_0, t = 0): it is the cost of CHP installation.
- Annual Net Cash Flow for N Years (F_t, t = 1 to N) is given by Equation (3.7) (Nkoi, B., et al., 2015):

$$\boldsymbol{F_t = (Ce + Re + Ch + Rh - Co/m) \ldots\ldots\ldots (3.7)}$$

Where:

C_e = saved cost of electricity or the cost of electricity that would be purchased from the grid, if not cogenerated (current situation on the plan).

R_e = revenue from selling excess electricity, if any.

C_h = saved cost of heat, i.e. cost of heat that, if not cogenerated, would be produced by boiler(s).

R_h = revenue from selling excess heat (not available in this case study).

$C_{o/m}$ = operation and maintenance cost (except fuel) of the cogeneration plant in this case study.

3.4.4. Internal rate of return IRR

Internal rate of return is defined as the discount rate that results when NPV value is zero. This reveals that IRR is the discount rate that makes NPV worth of future cash flows equal the CHP initial capital investment cost. Equation (3.8) below is used to determine IRR (Internal rate of return),

IRR = d, for NPV = 0 (Nkoi, B., et al., 2015) (Budzianowski, W. M., and Dominika A., 20105).

$$\mathbf{0 = -F_0 + \sum_{t=0}^{N} \frac{Ft}{(1 + dt)t}} \text{............ } \textit{(3.8)}$$

Assumptions:

- The operation starts from the beginning of the first year, t = 1.
- Initial capital investment cost F_0 in Construction period is assumed as year t = 0
- A life cycle period of 20 years is chosen, (that is N = 20).
- Annual operating hours in terms of annual electricity generation is 8000 hours.
- Availability of implementing on-site generation plant ~ 95%.

3.4.5. Escalation rate

Escalation rate is the changes in the levels of prices by prevailing the economic conditions (Hollmann & Dysert 2007) such as changes in productivity, supply, technology, labour shortage, market demand, and profit margin influence price escalation. Escalation rate is the market rate at which cost of items annually increases. In CHP, escalation applies to cost of fuel, electricity and operation/maintenance.

3.4.6. Investment/Capital cost

Capital cost of investment refers to the total cost of construction/installation of the CHP plant (NkoiB et al., 2015). This includes:

- Equipment cost: This cost entails purchase of equipment, taxes, and the transportation. The cost depends on the size of the system, components and specifications. This equipment consist mostly of the prime mover and the generator set.
- Installation costs: This consists of all permits of the installation, documentation, grid connections and including reinforcement of local/national electricity networks.
- "Soft" costs: management of the construction fees, environmental aspects, training, legal fees and additional costs under certain financial arrangements such as (bank fees, interest paid during the construction, and debt insurance). (EDUCOGEN, 2001; Stromberg et al, 1993).

3.4.7. Interest rate

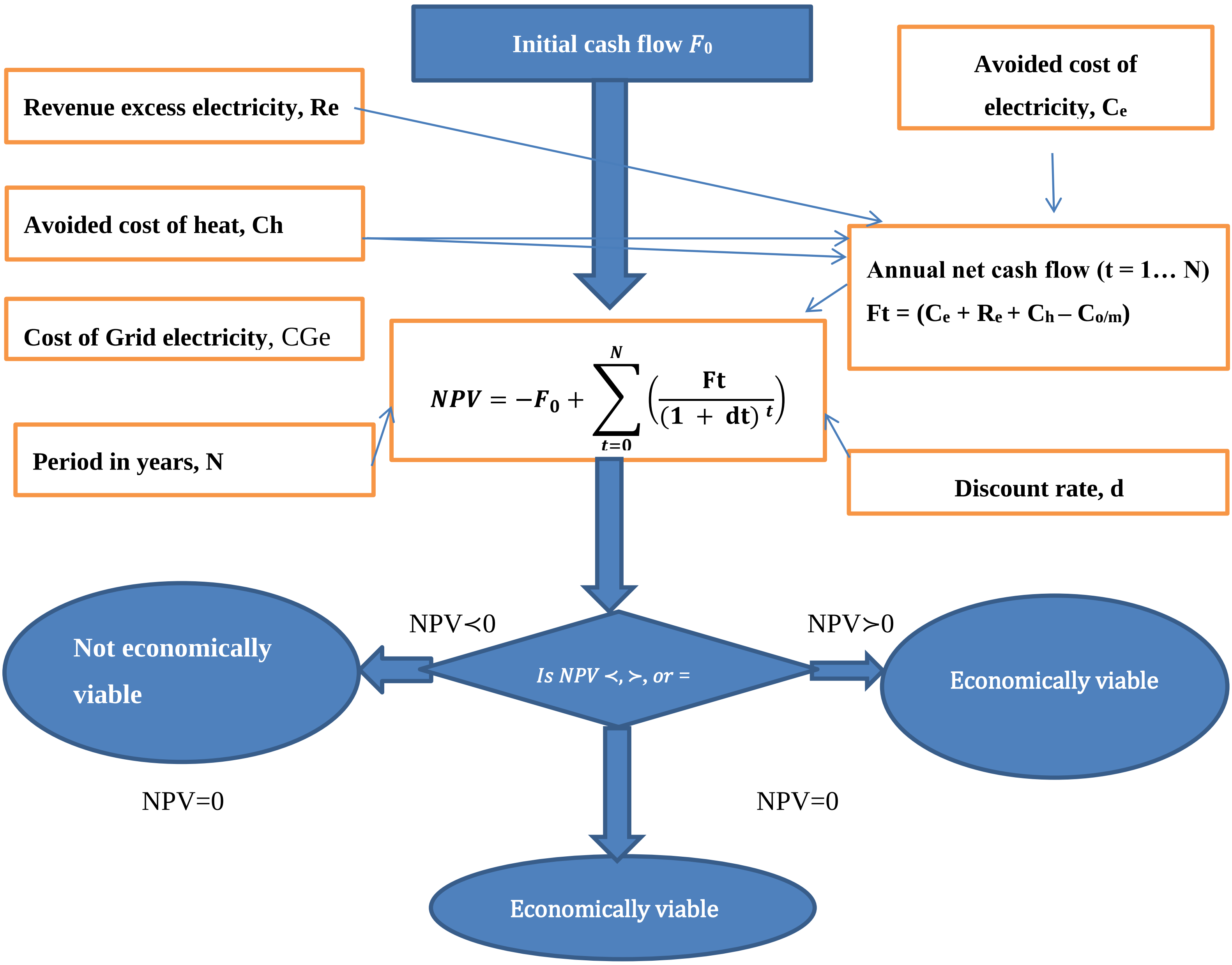
Interest rate is defined as the percentage of a principal from adjutant to a debit for using of assets. Interest rates are known as the annual percentage rates (APR). If the borrower has a low-risk party, they will be often charged a low interest rate; if the borrower is considered as high risk, the interest rate that they are charged will be higher. In Algeria, The interest rate is recorded at 3.50% in 2017. With a history of, averaged 5.23 % from 1963 until 2017, it reached to 21 percent in December of 1994 and recorded in January of 1972 a low value of 2.75 percent (Trading Economics, 2017)

3.4.8. Profitability index

The profitability index rule is defined as the variation of the net present value (NPV) rule. The profitability index (PI) is the present value of the project's future cash flows divided by the initial cost of investment.

$$PI = \frac{PRSENT\ VALUE}{INITIAL\ COST} \quad (3.8)$$

A PI greater than 1.0 indicates that profitability is positive and the project considers accepted, while a PI of less than 1.0 indicates that the project will be having a financial risk and lose money. As values on the profitability index increase, so the financial of the proposed project becomes more attractive. In general, the profitability index would be greater than 1 if NPV > 0. If NPV < 0, the profitability index would be below 1 and the project is financially risky. Hence, the calculations of profitability index and NPV would both lead to the same decision as regards whether to go ahead or reject a project (Profitability Index, INVESTOPEDIA)



Flowchart 3- 2 chart for NPV computation

3.5. Using Metrics to Support Decisions

The metrics described in the previous section will be calculated and compared all of them to the payback period method. Alternative compares current operation of conventional case to the CHP project with assuming constant biogas production over the planning horizon, while alternative 2 compares the current operation of conventional case to an escalated CHP project, assuming a 2% annual increase in biogas production and escalation of power costs at 1%. Financial evaluation of any project depends on the assumptions (the same with the case study presented in the literature section 2.13. For each metric, the calculated values (e.g., discount rate, project costs, project maintenance). The differences between alternative 1 and alternative 2 are assumptions about biogas production and escalation of costs. So, for the financial analysis, how can uncertainty in assumptions that affect financial evaluation be better understood?

3.6. Energy Cost (Fuel and Grid Power)

Energy cost of a CHP comprises cost of conventional case (grid purchased)**.** Electricity and fuel cost are given per unit power consumption. Total cost of electricity purchased is obtained by Equation 3.10 below while fuel cost is given by Equation 3.11 (Nkoi, B., et al., 2015).

Electricity cost = electricity tariff $/kWh × kWh of electricity consumed (3.10)

Fuel cost = Gas tariff $/kWh × kWh of power generated (3.11)

3.7. Risk Assessment of CHP Project

Based on the uncertainty of input variables, a risk-assessment technique that can be related to NPV, PI, IRR and payback period to statistically calculate the output range. Even if there are two projects having the same NPV and IRR results, one project can be more risky than another. Risk assessment is used for understanding the impact of the risk factor from uncertain assumptions and answers on the project benefits and costs. For example, in such case the viability of the CHP project is highly dependent on the price of the alternative sources of energy input, which is highly uncertain in the long run. Changes in the price of power, for example, may cause reduction in the project’s NPV because the benefits of investing in biogas use decrease. Also risk assessment can give decision makers insight into which factors of the same project could pose the greatest risk to a project's business case.

CHAPTER 4. RESULTS AND DISCUSSION

Outlines

1. Introduction.
2. Evaluation of Conventional Energy.
3. Reciprocating Gas Spark Ignition Engine.
4. Economic Analysis of Park Ignition Engine.
5. Life Cycle Cash Flow.
6. Result discussion.

4.0. Introduction

This chapter summarizes the annual energy consumption, the fuel energy input of the produced biogas from the digester per year, sizing of CHP technology and the system performance in WWTP EL KARMA. Energy input and output of CHP plant is compared with the conventional case (energy from grid system) and the results from assuming two alternative scenarios presented in section 3.7 the constant and escalated values.

4.1. Evaluation of the Conventional Energy Consumption in WWTP El Karma

4.1.1. Electricity consumption in WWTP el karma

Table 4. 1: Annual Electricity Consumption in WWTP El Karma

Month	Electricity consumption kWh
January	278546
February	370071
Mars	515504
April	616713
May	556155
June	579835
July	550433
August	511492
September	639154

October	243168
November	386800
December	863000
Total	6110871

The electricity price ratio in industrial sector in Algeria 2016 is 0.035 $/kWh

Using the equation presented in section 3.8.

Grid Electricity Cost / Year in WWTP El Karma = 213880 $

4.1.2. Gas consumption

Based on characteristic of the boilers in WWTP El Karma mentioned in section 3.4.1.

- The biogas burnt in the boilers (efficiency of 80%) = 1800 kW × 0.80 = 1440 kW.
- LHV of biogas produced in WWTP El Karma based on the data from table 3.1 is 6.53 kWh/ m^3.
- The hourly volume that enters to produce heating:

$$\textbf{Volume} = \frac{\textbf{ActualPower}}{\textbf{LHV}}\ \mathbf{m^3/h}$$

$$\textbf{Volume} = \frac{1440}{6.53} = 220.52\ \mathbf{m^3}/h$$

- The working time per year of the boiler is:
  - 12 hours over 24 hours during 6 months (spring, summer).
  - 24 hours over 24 hours during 6 months (autumn, winter).
- The average volume of biogas burned per day can be calculated as a function of the time of year: Volume = (Volume / Hour) × no. of hours/day

= 220.52 × 12= 2646.24 m^3/day (spring, summer).

= 220.52 × 24= 5292.48 m^3/day (autumn, winter).

The calculation result of heat consumption from biogas is given in Table 4.**2**

Table 4. 2: Annual Heat Consumption of WWTP El Karma

Boiler		**LHV**
Thermal Power	1800 Kw	6.53 kWh/m^3
Efficiency	80%	

Actual power	1440 Kw	

Table 4. 3: Biogas consumed by the boiler per month

The average volume of biogas burned per day (spring, summer).	2646.24 m^3/day
The average volume of biogas burned per day (autumn, winter).	5292.48 m^3/day
Annual Heat consumption (kWh)	9331200 kWhth

4.2. Reciprocating Spark Engine CHP Performance

The reciprocating Gas Spark Ignition Engine CHP system 4 stated in section with nominal capacity 3326 kW is chosen for this project based on the energy input available from the amount of biogas produced on site even with applying escalation rate of 2% on biogas production. With performance parameters of:

- Total System Efficiency of CHP is 80%,
- Electrical efficiency 41% and thermal efficiency 39%,
- 10% of energy output consumed by CHP and,
- 10% heat loses, with assumption of 8000 hours/ year.
- Annually Energy input with fixed amount of biogas = amount of biogas × LHV

= 3888000 × 6.53 = 25388640 kWh= ***3173 kW***

Annual electrical energy generated = 0.41 × 25,388640 = ***10,410,000kWh***

Annual thermal energy generated = 0.39 × 25388640 = ***9,900,000kWh***

- ***With applying the escalation rate 2%***

- Annually Energy input = amount of biogas × LHV

= (0.02×3888000+3888000) × 6.53 = ***3237 kW***

Annual electrical energy generated = 0.41 × 25,388640 = ***10,617,529 kWh***

Annual thermal energy generated = 0.39 × 25388640 = ***10,099,600 kWh***

4.3. Economic Analysis of Reciprocating Spark Ignition Engine CHP

Assumptions:

The operation of the plant starts from the beginning of the first year, $t = 1$.

Construction period is assumed as year $t = 0$ which takes capital cost F_0

A life period of 20 years is chosen, (that is $N = 20$).

4.3.1. Initial cash flow (investment cost)

The costs of nominal capacity of 3326 kW is spelled out in table 2.10. The total plant cost consists of total equipment cost plus installation labour and materials (including site work), engineering, project management (including licensing, insurance, commissioning and start up.

- Initial cash flow F_0 = 3326 × capital cost per KW
- Initial cash flow = 3326 × $ 1300 kW
- Initial cash flow F_0 = 4323800 $

4.3.2. Year 1 annual net cash flow

These costs typically include:

- Maintenance labour,
- Engine parts and materials such as oil filters, air filters, spark plugs, gaskets, valves, piston rings, electronic components, etc. as mentioned in section 2.8.4.7 and table 2.10.
- Annual Operation & maintenance cost, Co/m = total annual energy generated (kWh) × O&M cost per kWh

  (Annual electricity generated (kW) + annual heat generated (kW)) ×O&M cost per kW = 20310000 × 0.002 = **40620 $**
- Annual revenue from excess electricity exported to grid, Re

  = annual electricity exported (kWhe) × electricity feed in tariff (0.14) per kWhe

  = 5161266 × 0.14 = **722578 $**
- Annual saved electricity cost = annual electricity consumption from CHP (kWhe) × Electricity tariff per kWhe = 5248734 × 0.035 = **183706 $**

Annual saved heat cost = annual heat consumption from CHP (kWh) × gas oil price per kWh = 9331200 × 0.0033 = **30793 $**

- Net benefit for year 1 = 896500 $

4.4. Life-Cycle Cash Flow of Reciprocating Gas Spark Ignition Engine with escalation rate on the costs.

Applying the escalation rates of prices (costs) by 1% on electricity and heat prices and 1% of operation and maintenance cost to the life-cycle as explained in section 3.5, the life-cycle cash flow of the cycle CHP case was computed and result is as shown in Table 4.3. With these considerations:

Hours Of CHP Operation/Annum:8000

Electricity Tariff From Grid $/Kwh:0.035

Gas Tariff From The Grid$/Kwh=0.00334

Feed In Tariff of electricity = 0.14$/Kwh

CHP Capital Cost $/Kw:1300

Initial Investment Cost $= 4323800

Table 4. 4: ***Techno-Economic Analysis of CHP of Escalated Values***

O&M 1% escalated	Year	Annual income (escaled1%)	Annual saved (escalation rat 1%)	annual net Cash flow	Present value
0	0	0	0	-4323800	4323800
-40600	1	630932.12	244674	916206.12	880967
-41006	2	637241.4412	247120.74	596237.4412	551255
-41416.06	3	643613.8556	249591.9474	602200.7956	535354
-41830.2206	4	650049.9942	252087.8669	608223.7736	519912
-42248.52281	5	656550.4941	254608.7455	614306.9713	504916
-42671.00803	6	663115.9991	257154.833	620450.991	490351

-43097.71811	7	669747.159	259726.3813	626656.4409	476207
-43528.6953	8	676444.6306	262323.6451	632923.9353	462471
-43963.98225	9	683209.0769	264946.8816	639254.0947	449131
-44403.62207	10	690041.1677	267596.3504	645647.5456	436176
-44847.65829	11	696941.5794	270272.3139	652104.9211	423595
-45296.13487	12	703910.9952	272975.0371	658626.8603	411376
-45749.09622	13	710950.1051	275704.7874	665214.0089	399510
-46206.58719	14	718059.6062	278461.8353	671867.019	387986
-46668.65306	15	725240.2022	281246.4536	678586.5492	376795
-47135.33959	16	732492.6043	284058.9182	685373.2647	365926
-47606.69298	17	739817.5303	286899.5074	692227.8373	355371
-48082.75991	18	747215.7056	289768.5024	699150.9457	345121
-48563.58751	19	754687.8627	292666.1875	706143.2752	335166
-49049.22339	20	762234.7413	295592.8493	713205.5179	325498

Table 4. 5*:* Techno-Economic Analysis of CHP of constant values

Fixed O&M	Year	Annual income	Annual saved	annual net Cash flow	Present value
-40600	0	0	0	-4323800	-4323800
-40600	1	601077	244674	805151	774184
-40600	2	601077	244674	805151	744407
-40600	3	601077	244674	805151	715776

-40600	4	601077	244674	805151	688246
-40600	5	601077	244674	805151	661775
-40600	6	601077	244674	805151	636323
-40600	7	601077	244674	805151	611849
-40600	8	601077	244674	805151	588316
-40600	9	601077	244674	805151	565688
-40600	10	601077	244674	805151	543931
-40600	11	601077	244674	805151	523011
-40600	12	601077	244674	805151	502895
-40600	13	601077	244674	805151	483553
-40600	14	601077	244674	805151	464955
-40600	15	601077	244674	805151	447072
-40600	16	601077	244674	805151	429877
-40600	17	601077	244674	805151	413343
-40600	18	601077	244674	805151	397445
-40600	19	601077	244674	805151	382159
-40600	20	601077	244674	805151	367460

Table 4. 6: Financial Results for Alternative Metrics

Item	Alternative 1 – Constant	Alternative 2 – Escalated
Capital Cost	**$4323800**	**$4323800**
Payback Period	**5.3 years**	**5 years**

Net Present Value	**$ 6629351**	**$ 8607752**
Project Action	**NPV > 0**	**NPV > 0**
PI	**2.5**	**2.8**
Project Action	**BCR >1**	**BCR >1**
Interest Rate, i	**3.5%**	**3.5%**
IRR	**18%**	**20%**
Project Action	**IRR > i, so consider accepting CHP project**	**IRR > i, so consider accepting CHP project**

4.5. Result Discussion

The outputs of CHP used as inputs for the techno-economic assessment of reciprocating spark ignition engine and calculating the Initial cash flow of installation costs of 3326 kW and the annual net cash flow with applying the escalation rates of prices (costs) to the life-cycle as spelled out in section 3.5.5 and 4.5.

The installation/capital cost is obtained as 4323800 $, while year (1) annual net cash flow is found to be 896547$. The present value of year (1) annual net cash flow is found to be 853854 $. The annual savings year (1) is estimated to be 214570 $ based of the energy prices in Algeria presented in section 2.1. The bulk of annual net cash flow of the plant comes from sales of excess electricity to the grid according to the feed in tariff resented in section 2.11.

The outcome of the Life-Cycle Cash Flow of reciprocating gas spark ignition engine indicates that: a positive and a high profit in NPV > 0 in both alternatives of constant and escalated values so, consider accepting CHP project. The payback period of 5.3 and 5 years and high IRR 18 and 20% with Profitability Index 2.5 and 2.8 which makes the project profitable with constant and escalated values respectively. Dependent on utility’s requirements for payback period of CHP project, this value can result in the project being accepted compared with the same case of The City of St. Petersburg with 12 and 11.6 years. Analysis also show which input assumptions cause the greatest variability in project NPV which is the escalated case. The regression results simulation indicate that the NPV is most sensitive to cost of power, as well as simulation results show that uncertainty in a project’s business case results can significantly impact the project’s outcome. For example, the results for alternative 1 demonstrate that a risk-weighted average of the project NPV increases with alternative two due to largely the changes assumed in costs of future power cost.

CHAPTER 5. CONCLUSION

5.1. Conclusion

Energy resources availability, as well as environmentally sustainable development, represent the major challenges faced by Algerian population and economy. The possibility of using resources which will not compromise the development of future generations, and simultaneously offer beneficial externalities beyond merely economic, has gained increased interest in last decades in Algeria.

Generally, Algeria is facing twofold issues: water and energy. For future planning and strategic policy considerations in Algeria, renewable energies and water are to be placed at the heart of energy and economy policies.

Hence, Algeria is engaged in the promotion of renewable energy resources in order to come up with sustainable and global solutions to mitigate present environmental challenges and also to preserve conventional energy resources. In these terms, the renewable energy program that Algeria has adopted takes into consideration all forms of renewable energy including biomass (waste valorization).

Algeria has also setup an ambitious program regarding the implementation of WWTPs and desalination plants. Energy demand of wastewater treatment plants is high. The sludge valorization in biogas to produce energy is important for energy efficiency of the WWTP and as long as WWTPs can experience efficiency, environmental, reliability, and economic benefits if implementing CHP technology. The CHP technology is particularly interesting in this case since it generates electricity and heat.

This study has analyzed energy efficiency in the WWTP of El Karma. Under the Algerian policy of Regulatory Order, fixing the guaranteed purchase price and the conditions of the application for electricity generated from facilities using renewable resources. Currently, this plant covers its electricity needs from the network. Most of the produced biogas is burned in a boiler to generate heat for the anaerobic digestion and the remained biogas is flared. The yearly electricity and heat consumptions are estimated at 6110871 kWh and 9331200 kWh, respectively.

A number of objectives were targeted in order to achieve the aim recalled in the preceding section. The main objective of this research, which is analysis of technical performances of CHP technology based on reciprocating gas spar ignition engines in WWTP El Karma of Oran Algeria. This objective is meant to establish the characteristics and performances of the engines that were subsequently convert biogas to heat and electricity power to meet the energy demand of the plant. From the work done in this part of the research, this aim can be said to have been achieved and concluded that:

The performance of the CHP is investigated within two costs variants (constant and escalated values) and compared to the current energetic situation of the plant which is the conventional way. When evaluating a potential project such as CHP technology, it is necessary to recognize that it is a long run project with a long term investment which requires a long term analysis. Each of the alternative methods used in this study recognizes the complete life of 20 years of an asset and measures the costs and benefits over this period. Several other critical components were also considered. The CHP is sized using all available biogas produced in the plant.

In this research, the methodology applied uses technical and economic inputs from the biogas plant as well as the CHP. The most important parameters retained in the economic appraisal of the CHP technology are: simple payback period (PBP), net present value (NPV), internal rate of return (IRR), and profitability index (PI).

NPV is very sensitive with respect to uncertain changes in amount of biogas produced, grid electricity cost, and electricity export tariff, were also investigated.

The following conclusions are attained:

- It is possible for the WWTP of El Karma to become not only energy independent by implementing a CHP technology but also electricity exporter to the grid. Indeed, the CHP outputs indicate that the annual electrical energy generated is 10,410,000 kWh and the annual thermal energy generated is 9,900,000 kWh with total system efficiency of 80%.
- The project is profitable: PI = 2.5-2.8
- The payback period is short: PBP = 5.3-5 years.
- The internal rate of return is high: IRR = 18-20% with constant and escalated costs, respectively.
- The NPV is most sensitive to cost of power.

Furthermore, this study clearly emphasizes how CHP as a technological innovation can impact the economic viability of WWTP El Karma by building an integrated energy system and saving money. As well as, it became clear that CHP plant will perform well as a business opportunity as long as economic incentives to electricity generation from CHP are retained at the long run and even with uncertain changes.

5.2. Recommendation

In ALGERIA, the future development of water treatment depends on solutions characterized by high energy consumption. The biogas-to-energy conversion route offers the greatest number of projects that may be economically competitive, thus running without relying on subsidies from the state.

CHP technology for the biogas-to-energy conversion is an efficient approach for generating electricity and thermal energy output on site. It is an environmentally friendly technology of good repute that would be a measure for large heat and electrical energy savings and contribute to reduce global warming by reducing the amount of natural gas used for generating electricity. As well as, it offers a good business opportunity with among the sectors, CHP in WWTP El Karma offers a large potential of generating electricity and heat and economic attractiveness. As observed, CHP technology for Biogas to energy in WWTP is a favored only when the biogas potential reaches a critical supply that enables the existence of the benefits of economies of scale for a biogas processing plant.

So, it is observed that there is a high concentration of the energy potential in WWTPs, which suggests that the implementation of a bioenergy policy should be focused on zones of priority development organized hierarchically according to their potential or another equivalent criteria, and articulated by Algerian government.

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