LIFE CYCLE MANAGEMENT FOR INDUSTRIAL BIOGAS PLANT

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LIFE CYCLE MANAGEMENT FOR INDUSTRIAL BIOGAS PLANT

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DEPARTMENT OF
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I certify that thesis is submitted by Mehmet Volkan AKSAY titled as "LIFE CYCLE MANAGEMENT FOR INDUSTRIAL BIOGAS PLANT" is fully adequate sqope and quality as a thesis for degree Master of Science.

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This thesis is unanimously accepted by the examining comittee as a master degree thesis in the scope of Energy Systems Engineering. 15/ 01/ 2015

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"All the information in this thesis has been obtained in accordance with academic rules and ethical principles, and offered, and also derived from this study as required by these rules and principles, I declare that I did all of the citations."

Mehmet Volkan AKSAY

ABSTRACT

M. Sc. Thesis

LIFE CYCLE MANAGEMENT FOR INDUSTRIAL BIOGAS PLANT

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Graduate School of Natural and Applied Sciences
Department of Energy Systems Engineering

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Energy demand is constantly increasing because of rapid industrialization, Population growth and uncontrolled urbanization. These energy demands mostly supplied from fossil fuels therefore intensify the natural greenhouse effect, causing global warming and environmental pollution. Therewithal insufficient recycling and disposal of organic wastes cause environmental problems. Depending cheap energy and raw materials search of the world and the environmental pollution, green energy sources became more important. These organic wastes are used to produce biogas and fertilizer with anaerobic digestion system. Biogas from anaerobic digestion system is used in cogeneration system as a fuel to produce electricity and also can be burn for heating. Methane is believed to be a significant cause of climate change. By capturing methane and using it as fuel, preventing it from releasing into the atmosphere. Life cycle assessment (LCA) is a comprehensive ecological evaluation that describes energy, material, waste flow of a product and their effect on the environment. It aims to identify every change during the life cycle and shows environmental benefits and cost savings. Life cycle management (LCM) is the process of managing the entire lifecycle of a product or system from beginning, progresses through engineering design and manufacture, to service and disposal of manufactured products. This process defines the largest components of the system cost and determines its utility. This thesis has been prepared as an application of life cycle management approach to succeed in energy and waste management for an industrial biogas plant. The Project comprises environmental and economic assessment of an industrial anaerobic digestion (AD) plant and biogas recovery system.

Keywords **:** Life cycle, biogas plant, biogas, recycle, energy, environment, waste to energy.

Science Code **:** 914.1.038

ÖZET

Yüksek Lisans Tezi

ENDÜSTRİYEL BİYOGAZ TESİSLERİNDE YAŞAM DÖNGÜSÜ YÖNETİMİ

Mehmet Volkan AKSAY

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Enerji ihtiyacı, hızlı endüstrileşme, nüfus artışı ve kontrolsüz şehirleşme sebebiyle hızla artmaktadır. Bu enerji ihtiyacı çoğunlukla fosil yakıtlardan elde edilir bu yüzden doğal sera gazı etkisi artar küresel ısınma ve çevre kirliliğine sebep olur. Bununla beraber organik atıkların yetersiz geri dönüşümü ve bertarafi çevresel sorunlara yol açmaktadır. Dünyanın ucuz enerji ve hammadde arayışı ve çevre kirliliği sebebiyle yeşil enerji kaynakları daha önemli hale gelmiştir. Organik atıklar anaerobik çürütme ile biyogaz ve gübre üretimi için kullanılmaktadır. Anaerobik çürümeden elde edilen biyogaz kojenerasyon sisteminde elektrik ve ısı üretmek amacıyla yakıt olarak kullanılmaktadır. Metan gazı iklim değişikliğine önemli bir şekilde etki etmektedir. Metan gazını yakıt olarak kullanarak atmosfere salınması engellenmektedir. Yaşam döngüsü analizi (YDA), bir ürünün enerji, madde, atık akışlarının kapsamlı değerlendirilmesini ve çevreye olan etkilerini içermektedir. Yaşam döngüsü analizi, yaşam döngüsü sırasındaki bütün değişiklikleri açıklamayı amaçlar ve çevresel faydalarını ve maliyet tasarrufunu gösterir. Yaşam döngüsü yönetimi (YDY) bir ürünün veya sistemin tüm yönetim işleyişini baştan başlayıp, mühendislik tasarımı ve üretimden servis ve bertarafa kadar takip eden işleyiştir. Bu işleyiş sistem maliyetini en geniş bileşenleriyle tanımlar ve kullanımını belirler. Bu tez yaşam döngüsü yönetimi uygulamasını endüstriyel biyogaz tesisinde enerji ve atık yönetiminde başarılı uygulanması için hazırlanmıştır. Proje endüstriyel anaerobik çürütme tesisi ve biyogaz geri dönüşüm sisteminin çevresel ve ekonomik değerlendirmesini içerir.

Anahtar Sözcükler : Yaşam döngüsü, biyogaz tesisi, biyogaz, geri dönüşüm, enerji, çevre, atık enerji.

Bilim Kodu : 914.1.038

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SYMBOLS

m^3 : Cubic meter
J : Joule
PJ : Petajoule (10^{15} Joules)
kg : kilogram
h : hour
y : year
kg : kilogram
kW : kilo Watt
L : Liter
meq/L : milli equivelent per liter
pH : power of Hydrogen
€ : Euro

ABBREVIATIONS

AD : Anaerobic Digestion
ORC : Organic Rankine Cycle
WHO : World Health Organization
IEA : International Energy Agency
EPA : Environmental Protection Agency
LCM : Life Cycle Management
LCA : Life Cycle Assessment
LCC : Life Cycle Costing
TUIK : Turkish Statistical Institute
COD : Chemical Oxygen Demand
CHP : Combined Heat and Power

VS : Volatile Solids

DM : Dry Matter

CH_4 : methane

et al : and others

etc : Et cetera

CHAPTER 1

INTRODUCTION

Energy supply is considered worldwide as one of the most important challenges of the future. This challenge has ecological and economical aspects that are affiliated with each other. Today, the energy sector together with the transport sector is the main driver of the greenhouse effect, causing global climate changes (WHO, 2005).

Additional effects such as resource depletion and acidification are caused by state of the art energy generation. In the future, due to our present level of energy consumption, it is predicted that there will be a 66% increase in the demand for worldwide energy by the year 2030 (IEA, 2005).

Life cycle management (LCM) is the process of managing the entire lifecycle of a product or system from beginning, progresses through engineering design and manufacture, to service and disposal of manufactured products. Therefore this thesis contains environmental and economic evaluation of pilot plant. We will apply LCA for environmental evaluation, LCC for economical evaluation of pilot plant.

Life cycle assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product, such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use, land use, and noise—and others (Rebitzer et. al., 2004).

The LCC analysis takes the investment costs and costs in operation of all phases into account. In general, LCC yields present value of current and future expenditures for procurement of building and operating and maintaining the building through its life.

As the operational costs make up the main part of the total costs over the whole lifetime of a building, the LCC comparison of different scenarios creates the necessary transparency for the decision-making process (Hunkeler et. al., 2008).

The selected pilot plant is located in Kandıra consists of AD plant and biogas recovery systems to produce biogas by using different raw materials such as cattle, poultry manure and whey cheese during fermentation process.

Kandıra is a county in Marmara region of Turkey that belongs to the city name of Kocaeli. Marmara region is the most industrialized region of Turkey therewithal has a great potential for supply of raw materials and biogas production.

CHAPTER 2

REVIEW OF LITERATURE

2.1. BIOGAS

Biogas is mixture of methane and carbon dioxide produced by the bacterial decomposition of organic materials in the absence of oxygen (EPA, 2014).

Biogas can be produced from household wastes, manure, or agricultural crops and broken down by micro-organisms in anaerobic digesters and wastewater treatment plants. Biogas can be used for heating, to generate electricity by co-generation systems and vehicle fuel. And the leftover digested manure can be used as fertilizer, bedding, mulch and potting soil.

Biogas is produced in different environments, e.g., in landfills, sewage sludge and bio waste digesters during anaerobic degradation of organic material. Methane, which is the main component of biogas, is a valuable renewable energy source, but also a harmful greenhouse gas if emitted into the atmosphere. Methane, upgraded from biogas, can be used for heat and electricity production or as biofuel for vehicles to reduce environmental emissions and the use of fossil fuels. Biogas is considered a carbon dioxide-neutral biofuel and if used as vehicle fuel, emits lower amounts of nitrogen oxide, hydrocarbon and carbon monoxide emissions than petrol or diesel engines (Wellinger et. al., 2000).

Depending on the source of organic matter, biogas typically contains 50-70% methane, 30-40% carbon dioxide, and trace amounts of other constituents, such as hydrogen, hydrogen sulfide, nitrogen, and siloxanes (EPA, 2014).

The methane gas absorbs heat in the atmosphere 23 times better than carbon dioxide gas, so reduction amount of harmful methane gas, is short solution for confronting with earth warming (Samimiã et. al., 2012).

The most prevalent gas was methane, comprising 88 % of all waste emissions. A main driving force of CH_4 emissions from managed waste disposal on land is the amount of biodegradable waste going to landfills. In addition, CH_4 emissions from landfills are influenced by the amount of CH_4 recovered and utilized (combustion of biogas for electricity and/or heat generation) or flared. The share of CH_4 recovery has increased significantly in EU since 1990. The emission reductions are also partly due to the implementation of the Landfill Directive or similar legislation in the Member States (EU Commission, 2014).

The demand for renewable fuels is increasing due to the EU's commitment to reducing the greenhouse effect of climate change.

2.1.1. Biogas Potential of Turkey

Turkey creates a great demand for energy supply, which is mainly dependent on external resources. In this manner, local and renewable energy alternatives, including the production of biogas from agro-based organic materials, have become quite important. Governmental support for renewable energy production attracted not only national but also international energy companies, which resulted in an increasing number of new business activities in the production of renewable energy, including the production of biogas from agro-based organic materials such as animal manure, green house wastes and other agricultural organic wastes related to food production (e.g. cheese whey wastewater, olive mill effluent etc.) in Turkey.

In addition to agricultural organic wastes, organic fractions of municipal solid wastes which have been dumped or landfilled so far, and wastewater treatment sludge also offer possibilities for producing a great amount of biogas using modern biogas production solutions in Turkey (Azbar, 2014).

The agricultural sector employs 27.6% of the population in Turkey. Livestock constitutes one-third of all agricultural activities. Turkey's land area is 78 million hectares; with an arable land area of 28 million hectares. This corresponds to 36% of the total land area. Field crops are grown in the majority of agricultural fields. According to the last agricultural census (2009) in Turkey, there are a total of 3,076,650 agricultural enterprises, and approximately 70% of these farms are running livestock farming. The best way to manage these wastes in an environmentally friendly way is to recover the bioenergy and fertilizer value of these wastes via biogas technologies.

Turkey's calculated biogas potential is about 2.18 billion m3 (2.18 Gm3) by using animal numbers of TUIK in 2009. 68% of the total biogas potential is of cattle origin, 5% of small ruminant and 27% of poultry origin. The potential of Turkey's biogas energy equivalent is about 49 PJ (1,170.4 ktoe). Similar works that were carried out in this area indicate a gross biogas potential of 3,302.85 million cubic meters and 2,350 ktoe (ton petroleum equivalent) from animal wastes in Turkey (N. AZBAR, 2014).

Table 2.1. Comparison of the potential of biogas sector (Turk-German Biogas Project, 2011).

Sector	Theoretical Biogas Potential [PJ/year]	Technical Biogas Potential [PJ/year]
Agriculture - Livestock	144,4	78,4
Agricultural wastes	305,3	36,1
Energy Crops	325,1	81,3
Agro - Industry wastes	16,6	14,8
Municipal wastes	22,0	11,0
TOTAL (Energy crops included)	**813,4**	**221,5**
TOTAL (Energy crops excluded)	**488,3**	**140,3**

2.2. ANAEROBIC DIGESTION (AD) AND BIOGAS PLANTS

2.2.1. Anaerobic Digestion

AD is a microbiological process of decomposition of organic matter, in the absence of oxygen, common to many natural environments and largely applied today to produce biogas in airproof reactor tanks, commonly named digesters. A wide range of micro-organisms are involved in the anaerobic process which has two main end products: biogas and digestate.

Biogas is a combustible gas consisting of methane, carbon dioxide and small amounts of other gases and trace elements. Digestate is the decomposed substrate, rich in macro- and micro nutrients and therefore suitable to be used as plant fertilizer (Al Seadi, 2008).

All energy flows in the biogas systems were identified and summarized from a life-cycle perspective, and compared with the biogas yield. The raw materials, recovery technologies, conversion technologies, and transportation demands included, as well as the system boundaries applied, are shown in Figure 2.1. The arrows indicate energy or material flows in the biogas systems studied. All calculations are based on data from literature reviews (Maria Berglund and Pal Börjesson, 2006).

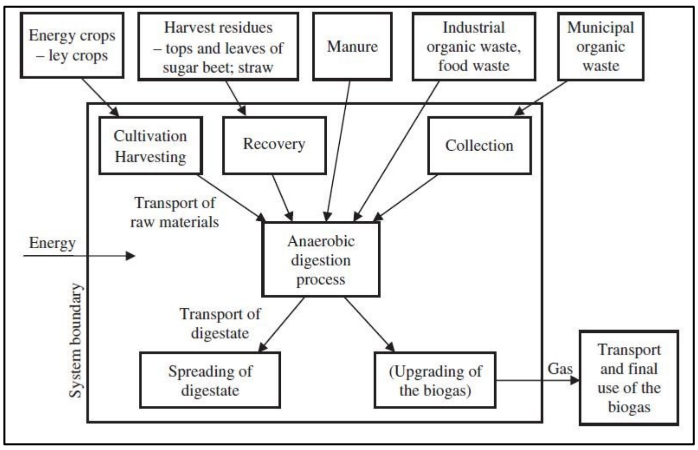

Figure 2.1. Overview of the biogas system studied. The arrows represent material or energy flows in the system.

The biogas produced in the anaerobic digestion tank and/or the post-digestion storage is used as fuel in a CHP module (Co-generation of Heat & Power) after cleaning of sulphur in either the post-digestion storage or a gas filter (Kathrine Anker Thyø and Henrik Wenzel, 2007).

2.2.2. Biogas Plants

Biogas plants are constructed according to its intended purpose by using different technologies.

Classification of the capacity of the biogas plant:

- Family type : 6 -12 m3 capacity
- Farm type : 50 -100 -150- m3 capacity
- Village type : 100- 200 m3 capacity
- Industrial-scale plants: 1000 - 10.000 m3 capacity

Types Of Fermentation Processes:

- Batch fermentation: A tank of fermenter or digester is fed with raw materials and sealed only allowing the gas to exit and then emptied completely after a fixed retention time.

- Semi-batch fermentation: Here fermenter or digester is initially filled with a certain proportion of organic matter and the remaining volume is complemented by equal daily amount. After a certain period of fermentation fermenters are completely emptied and refilled again.

- Continuous fermentation: Regular quantity of waste are fed into the fermenter continuously at a fixed rate regular quantity of material discharged, continuously.

The substrate must be fluid and homogeneous. This Fermentation is suitable for both medium and large scale waste treatment and large scale biogas production. Advantages of this type are constant and higher gas production.

A biogas plant consists of various biological, procedural, and energy conversion steps. The main item is the biogas vessel. Herein hydrocarbons are degraded into methane, carbon dioxide, trace gases, and biogas slurry by anaerobic bacteria. There are installations for mixing and heating its contents inside the vessel. Typically, combined heat and power plants (CHP) are attached to this vessel. In these CHP, biogas is converted into electric and thermal energy. Subsidiary installations e.g. pipes, pumps, hygiene installations, storages, gas conditioning facilities etc. are required to operate the plant. The majority of biogas plants are unique in form, so therefore a general example of a typical plant cannot be given. One possible construction is shown in Figure 2.2.

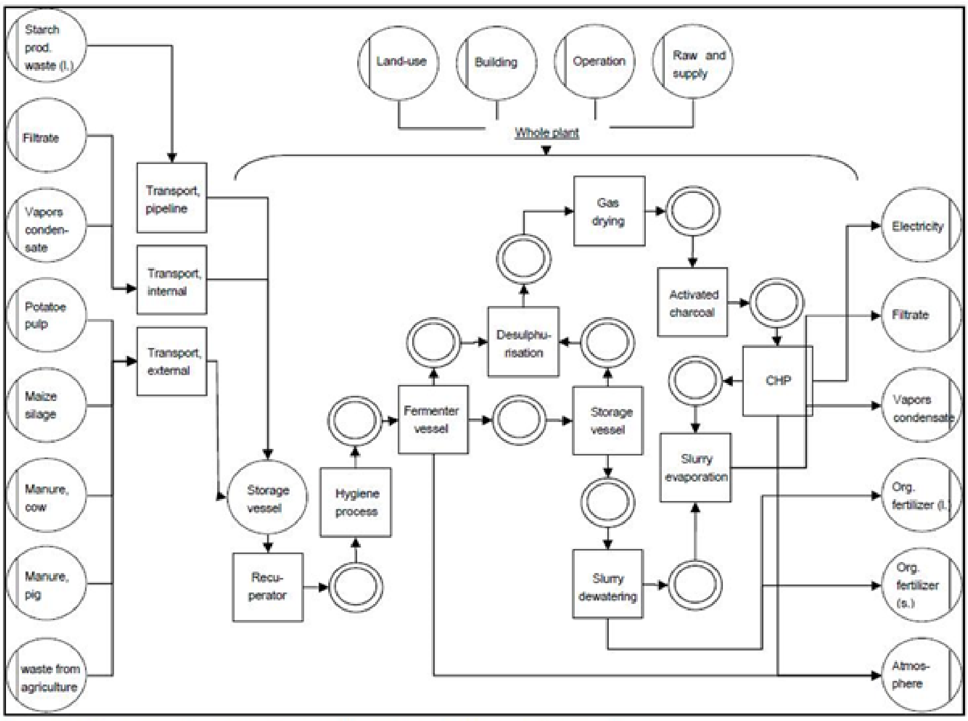

Figure 2.2. Possible constructions for biogas plants.

The biogas produced in industrial biogas digesters mainly consists of methane and carbon dioxide, but also small amounts of other gases such as hydrogen sulphide.

The later compound has corrosive properties causing damage on equipment and thus during industrial scale production the hydrogen sulphide has to be removed (Appels et. al., 2008).

Biogas can be biologically desulphurized in additional units, represented mainly by bio filters, bio trickling filters, and bio scrubbers, or directly into the anaerobic reactor, that is, by applying micro aerobic conditions during digestion. All these processes are based on the S cycle, and more specifically, in H2S oxidation. In the aforementioned extra units, H2S is solubilized in a humid packed bed where aerobic species of sulphide-oxidising bacteria (SOB) are immobilized and grown as a biofilm in the presence of O2 (Noyola et. al., 2006).

2.2.3. Benefits of Anaerobic Digestion and Biogas Plants

- Heat and power generation by using biogas as a fuel in cogeneration system(CHP)
- Produce clean energy from wastes
- Diverting organic wastes from landfills to digesters reduces methane emissions from landfills.
- Reduced CO^2 emissions of biogas in contrast to fossil fuels
- Produce high-quality, natural, low-carbon fertilizer
- Reduce carbon emissions by capturing methane
- Reduce pathogens
- Lower the odor from farm slurries
- Provides cleaner water
- Improves air quality and smell by capturing Hydrogen sulfide from wastes and burning during combustion.
- Usage of overproduction of energy crops, gains value in food markets

2.3. ORGANIC RANKINE CYCLE

Organic Rankine Cycle (ORC) is a closed Rankine cycle using organic fluids. Flue gas waste heat (150-400 ° C), Biomass, Geothermal energy, Solar energy is used as the heat source in the Organic Rankine Cycle. Organic Rankine cycle efficiency varies according to the temperature of the heat source and condensate (whether the hot water supply). Generally the efficiency (conversion of heat source to electricity) of heat sources over 250^{0}C is between % 19-25. Turbine efficiency is around 85%. Economic operating life is 20 years. ORC is used for electricity production from flue gas over 180^{0}C from industrial processes, exhaust gas from internal combustion engines and so on low temperature heat sources .

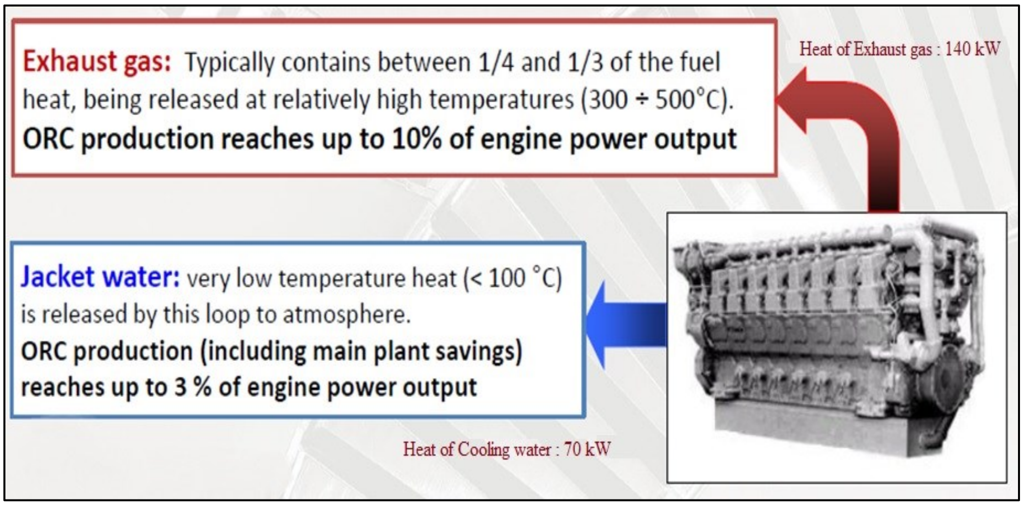

Figure 2.3. Definitions of exhaust gas and jacket water.

In ORC unit 140 kW heat from exhaust gas will be used. The heat ensured from engine cooling water will be used for heating fermenter in need of weather conditions as well as ORC unit. 70kw heat is needed for heating fermenters.

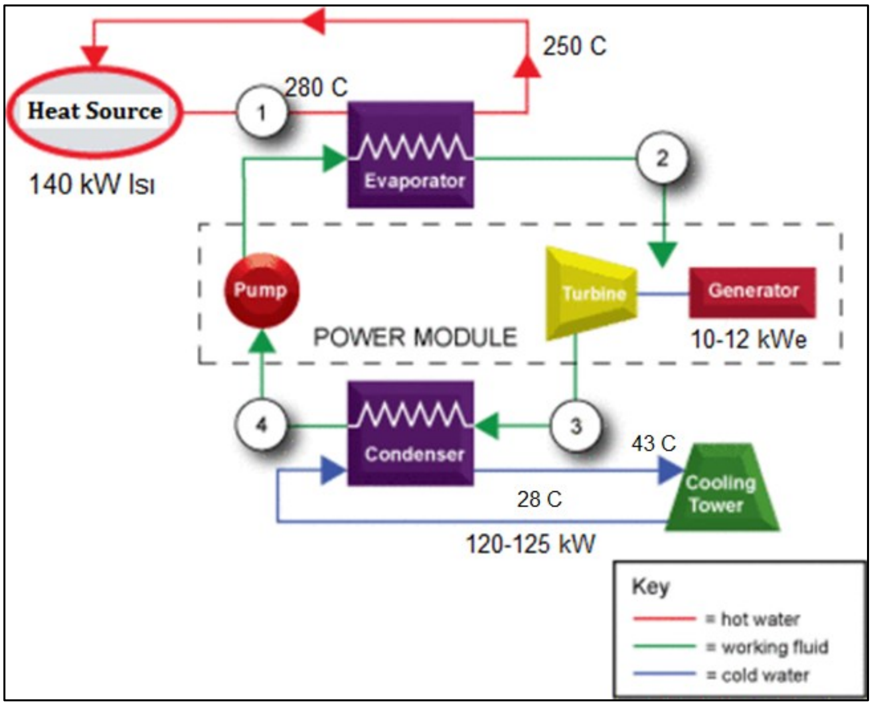

Figure 2.4. Organic Rankine Cycle flow diagram.

ORC system equipments are;

Evaporator is used to turn the liquid used in ORC unit (R245fa, R134a etc.) into its gaseous form.

Steam turbine: the fluid converted to superheated steam in evaporator passes turbine and rotates the blades of turbine, ensures mechanical energy. Mechanical energy is converted to electrical energy by generator that integrated to steam turbine.

Condenser is used to condense the wet vapor from steam turbine into liquid form. It can be water-cooled or air-cooled.

Pump is used to increase the pressure of the compressed organic liquid from condenser to evaporator pressure. The pressure depends on the fluid. For R245fa, evaporator pressure is 16 bar, condenser pressure is 2 bar.

2.4. LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an internationally standardized methodology (ISO 14040, 2006). LCA helps to quantify the environmental pressures related to goods and services (products), the environmental benefits, the trade-offs and areas for achieving improvements taking into account the full life-cycle of the product. Life Cycle Inventory (LCI) and Life Cycle Impact assessment (LCIA) are consecutive parts of a Life Cycle Assessment, where: Life Cycle Inventory is the collection and analysis of environmental interventions data (e.g. emissions to e.g. air and water, waste generation and resource consumption) which are associated with a product from the extraction of raw materials through production and use to final disposal, including recycling, reuse, and energy recovery. Life Cycle Impact Assessment is the estimation of indicators of the environmental pressures in terms of e.g. climate change, summer smog, resource depletion, acidification, human health effects, etc. Associated with the environmental interventions attributable to the life-cycle of a product. The data used in LCA should be consistent and quality assured and reflects actual industrial process chains. Methodologies should reflect a best consensus based on current practice (EU Commission, 2014).

Life-cycle-assessment (LCA), a product based environmental assessment method. This method takes into account all environmental effects of a product, including exploration of the resources, transport, manufacturing, emissions, and disposal (cradle to-grave). The environmental effects are clustered into impact categories, in which the collected data are correlated with each other. LCA is the most developed assessment tool for whole product systems. LCA provides background information for discussion within the expert public. They identify ecological needs and potential improvements in processes. Due to the flexibility of this method it can be applied to all types of production sectors, i.e. agriculture and forestry, industry, and service (Hartmann, 2006).

The LCA process is a systematic, phased approach and consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation as illustrated in Exhibit 1-2:

- *Goal Definition and Scoping* – Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.

- *Inventory Analysis* – Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).

- *Impact Assessment* – Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

- *Interpretation* – Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results (ISO14040, 2006).

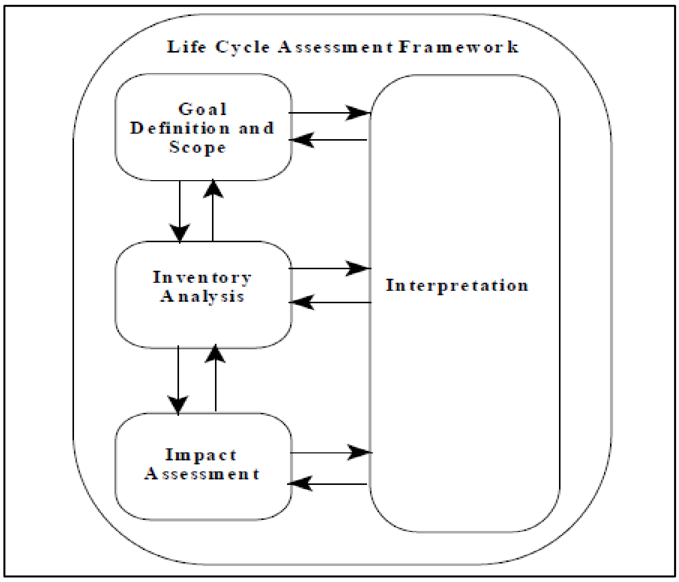

Figure 2.5. Life Cycle Stages (ISO14040, 2006).

The term “life cycle” refers to the major activities in the course of the product’s life-span from its manufacture, use, and maintenance, to its final disposal, including the raw material acquisition required to manufacture the product. Figure 2.6 illustrates the possible life cycle stages that can be considered in an LCA and the typical inputs/outputs measured (EPA, 1993).

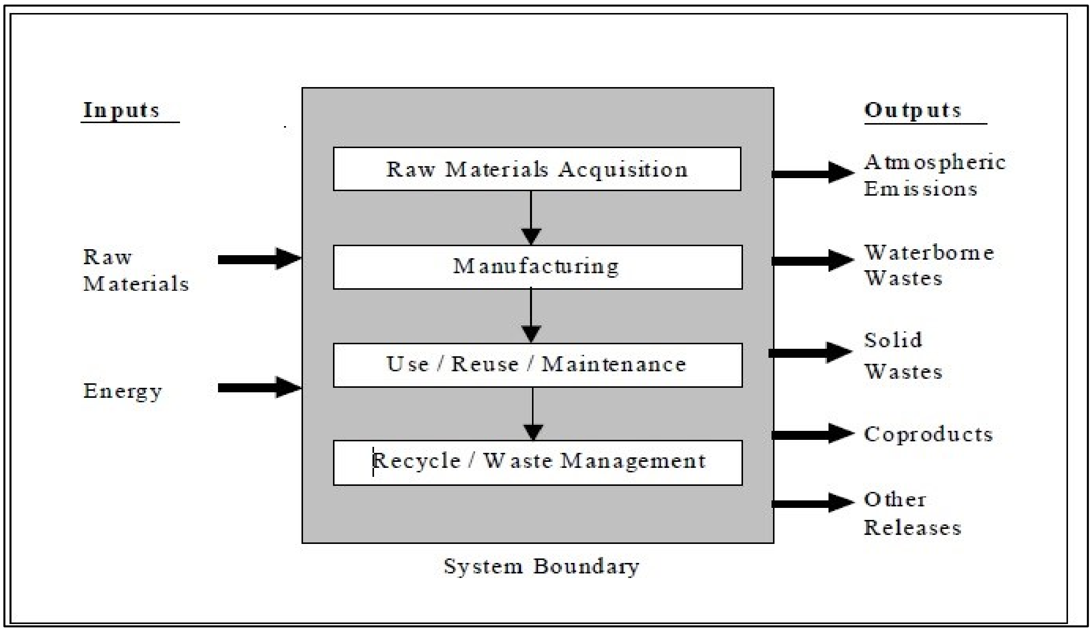

Figure 2.6. Life Cycle stages (EPA 1993).

Life cycle assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product, such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use, land use, and noise—and others (Rebitzer et. al., 2004).

Life cycle assessment (LCA) is a tool for evaluating environmental effects of a product, process, or activity throughout its life cycle or lifetime, which is known as a ‘from cradle to grave’ analysis. Environmental awareness influences the way in which legislative bodies such as governments will guide the future development of agricultural and industrial food production systems (Poritosh et. al., 2009).

Impact Categories and Associated Endpoints:

The following is a list of several impact categories and endpoints that identify the impacts.

Global Impacts:

Global Warming - polar melt, soil moisture loss, longer seasons, forest loss/change, and change in wind and ocean patterns.

Ozone Depletion - increased ultraviolet radiation.

Resource Depletion -decreased resources for future generations.

Regional Impacts:

Photochemical Smog - "smog," decreased visibility, eye irritation, respiratory tract and lung irritation, and vegetation damage.

Acidification - building corrosion, water body acidification, vegetation effects, and soil effects.

Local Impacts:

Human Health - increased morbidity and mortality.

Terrestrial Toxicity - decreased production and biodiversity and decreased wildlife for hunting or viewing.

Aquatic Toxicity - decreased aquatic plant and insect production and biodiversity and decreased commercial or recreational fishing.

Eutrophication – nutrients (phosphorous and nitrogen) enter water bodies, such as lakes, estuaries and slow-moving streams, causing excessive plant growth and oxygen depletion.

Land Use - loss of terrestrial habitat for wildlife and decreased landfill space.

Water Use - loss of available water from groundwater and surface water sources (EPA, 1993).

Life cycle interpretation is a systematic procedure to identify, qualify, check and evaluate information from the results of the LCI and/or LCIA of a product system, and to present them in order to meet the requirements of the application as described in the goal and scope of the study. The practitioner undertaking the LCA study should be in close contact with the commissioner throughout the study in order to ensure that specific questions are addressed. This communication also has to be maintained through the life cycle interpretation phase. Therefore, transparency throughout the life cycle interpretation phase is essential. Where preferences, assumptions or value choices are involved, these need to be clearly stated by the LCA practitioner in the final report (ISO14044, 2006).

2.5. LIFE CYCLE COSTING (LCC)

Life cycle costing is a methodology for the systematic economic evaluation of the life cycle costs over the period of analysis, as defined in the agreed scope (ISO 15685:5, 2008).

Life Cycle Costing (LCC) is a standard analytical method that calculates the total cost of an investment project or activity over its lifetime (EPA, 1993).

The approach of life-cycle cost analysis was used primarily as a tool to support investment decisions and complex projects in the field of defence, transportation, the construction sector and other applications where cost constitutes the strategic analysis of cost components of a project throughout its useful life.

The analysis methodology of Life Cycle Costing (LCC) concerns the estimate of the cost in monetary terms, originated in all phases of the life of a work, i.e. construction, operation, maintenance and eventual disposal / recovery. The aim is to minimize the combined costs associated with each phase of the life cycle, appropriately discounted, thus providing economic benefits to both the producer and the end user (Testa et. al., 2011).

LCC predates LCA, and distinct and different conceptual foundations and methodological approaches can be traced to its developmental roots in systems engineering (Blanchard 1978).

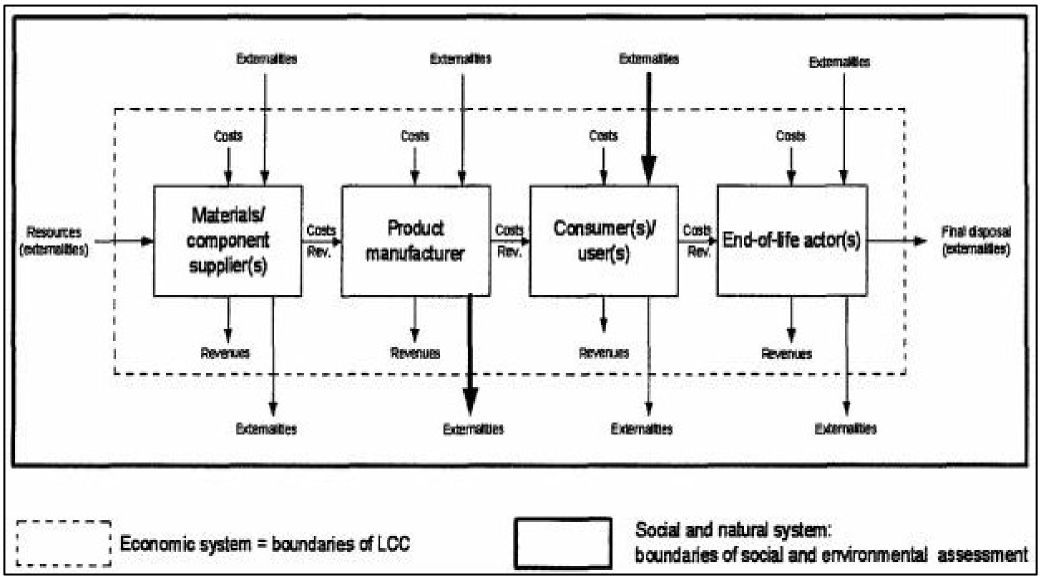

Figure 2.7. Life Cycle flow scheme for product.

In Figure 2.7 one can differentiate between:

1. Internal Costs along the life cycle of a product, with 'internal' implying that someone (a producer, transporter, consumer or other directly involved stakeholder) is paying for the production, use, or end-of-life expenses and, thereby, it can be connected to a business cost, and, indeed, liability. This concerns all the costs and revenues within the economic system (inside the dashed lines as represented in Figure 2.7).

2. External costs that are envisioned to include the monetized effects of environmental and social impacts not directly billed to the firm, consumer, or government, etc. that is producing, using, or handling the product. These are the so-named 'externalities' so popular in LCC and LCA debates, which are outside the economic system, though inside the natural and social system as illustrated in Figure 2.7 (Rebitzer et. al., 2004).

CHAPTER 3

LIFE CYCLE ASSESSMENT METHODOLOGY

The objectives of this study are to increase usage of renewable energy sources by using biogas potential and to ensure environmental and economic benefits in the selected pilot area, Kandıra-Turkey.

This project is an on field application project and it comprises anaerobic digestion biogas pilot plant in Kandıra. In this plant raw materials are different organic wastes such as cattle, poultry manure and cheese whey.

Cheese whey is a by-product of cheese production rich in proteins and lactose with a high organic matter content (up to 70,000 mg/l chemical oxygen demand COD), very high biodegradability (approximately 99%), and relatively high alkalinity (about 2500 mg/l CaCO3) (Mawson, 1994; Ergurder et. al., 2001).

Animal manure is a well-recognized potential source of a wide variety of infectious agents that can cause disease in humans, directly or indirectly, particularly through consumption of contaminated water or food (Millner, 2004).

Livestock production can result in methane (CH4) emissions from enteric fermentation and both CH4 and nitrous oxide (N2O) emissions from livestock manure management systems. Cattle are an important source of CH4 in many countries because of their large population and high CH4 emission rate due to their ruminant digestive system (IPCC, 2006).

Sweet whey, a potent pollutant, is produced inlarge quantities by cheese industries and in most cases is discharged without any treatment to rivers or streams (Ben-Hassan et. al., 1994; Ghaly et. al., 1989).

The impacts of raw materials to the environment are analyzed according to Life Cycle Assessment procedure. The utilization of renewable energies aims at the protection of human health, nature and resources. However, like any other kind of energy generation, the biogas process has an effect on the environment. In order to permit further development of energy technologies, it is important to be aware of the quality and quantity of effects caused. Effects on the environment can be measured by various methods. The most developed method for this purpose is the life-cycle-assessment (Hartmann, 2006).

3.1. GOAL AND SCOPE DEFINITION

The goal of this study are to increase the demand of AD plant and biogas recovery systems to produce biogas by using different raw materials such as cattle, poultry manure and whey cheese during fermentation process.

In this plant, different type of wastes and manures are processed with co-fermentation techniques and it creates a difference with other biogas systems.

When only the chicken (broiler) manure chosen as raw material, it cause poisoning inside the fermenter. Cheese whey has a low pH and it is rapidly hydrolyzed. Cattle manure has relatively low biogas production capacity but has high buffering properties. This plant aims %10 more biogas production is with co-fermentation of these 3 wastes.

It is the first AD biogas plants that produce extra electricity by organic Rankine cycle (ORC) system integrated with the waste heat of co-generation system in Turkey. By this system %5 of waste heat is converted to extra electricity.

Table 3.1. Goal definition of project.

Goal Definition	***Minimum Goal***
Stabilization of cattle manure	≥ 30 tons/day
Stabilization of broiler chicken manure	≥ 5 tons/day
Stabilization of cheese whey	≥ 15 tons/day
Production of biogas	≥ 833.000 m^3/year
Production of electricity from biogas	≥ 210 kW elektricity+240 kW heat
Production of solid fermented fertilizer	≥ 2.400 tons/year
Production of liquid fermented fertilizer	≥ 14.700 tons/year
Reduction of volatile solids in wastes	≥ %40
Reduction of chemical oxygen demand of wastes	≥ %40
Reduction of Greenhouse gas emissions	≥ %70

3.1.1. Primary Service and Functional Unit

The functional unit is the important basis that enables alternative goods, or services, to be compared and analyzed (Rebitzer et. al., 2004).

Functional unit of this study is %10 more biogas production with cofermentation of cattle manure, cheese whey, chicken (broiler) manure mixture. When only the chicken (broiler) manure chosen as raw material, it cause poisoning inside the fermenter. Whey cheese has a low pH and it is rapidly hydrolyzed. Cattle manure has relatively low biogas production capacity but has high buffering properties. This plant aims %10 more biogas production is with co-fermentation of these 3 wastes

It is the first AD biogas plant that produces extra electricity by organic Rankine cycle (ORC) system entegrated with the waste heat of co-generation system in Turkey. By this system %5 of waste heat is converted to extra electricity.

3.1.2. System Boundaries and Flow Charts

System boundaries of plant are shown below Figure 3.1.

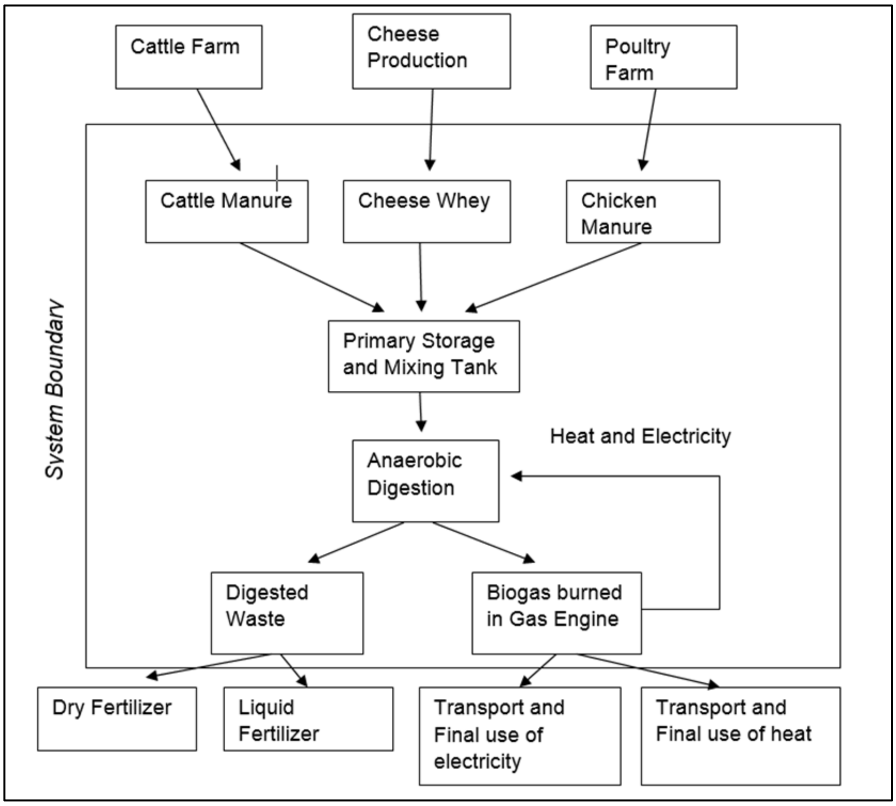

Figure 3.1. System boundaries of Kandıra biogas plant.

The definition of system boundaries determines which modules have to be part of the LCA. Various factors, such as time, money, and determinability of data influence the system boundaries. Ideally the system under investigation is defined in such a way that input and output flows are elementary flows at the point of the system boundaries. The modules which shall be included and which data quality should be obtained for each module of the LCA will be determined. Equally, each output flow has to be determined (Hartmann, 2006).

Cattle and chicken (broiler) manure from farm and whey cheese are stored and mixed in primary storage tank. Dry matter (DM) rate are adjusted as %12. Proses performed on mesophilic conditions (30^0-40^0 C). Biogas burned in Organic Rankine Cycle integrated co-generation system. Electricity and heat is used inside the plant. Remaining electrical and heat energy can transport and use other places. Dry and liquid fertilizers are produced from digested waste.

3.2. INVENTORY ANALYSIS

Life-cycle-assessment starts with the definition of goal and scope of the LCA study, the second step involves the construction of the inventory analysis, a systematic inventory of all energy and material flows, and emissions connected to the object under investigation during its entire life cycle. All data related to this constructed model are measured, calculated or estimated in regard of the data quality requirements defined in the goal and scope definition phase (Hartmann, 2006).

In this plant raw materials are different organic wastes such as chicken (broiler) manure cattle manure, and cheese whey.

Daily and yearly amount of wastes to be utilized in Kandıra plant are given Table 3.2

Table 3.2. Daily and yearly amount of wastes to be utilized in Kandıra.

Waste	Amount (tons/day)	Amount (tons/year)
Cattle Manure	30 tons	10.800 tons
Chicken(broiler)Manure	5 tons	1.800 tons
Cheese Whey	15 tons	5.400 tons

The amount of these wastes are great numbers but in Kandıra and around of Kandıra, supply of this raw materials are considered with the official numbers of population of these animals and amount of cheese production. Therefore supply of these raw materials will be easy and using these wastes in our plant will prevent contaminating water sources, soil and odor. Briefly it will bring environmental and economical benefits.

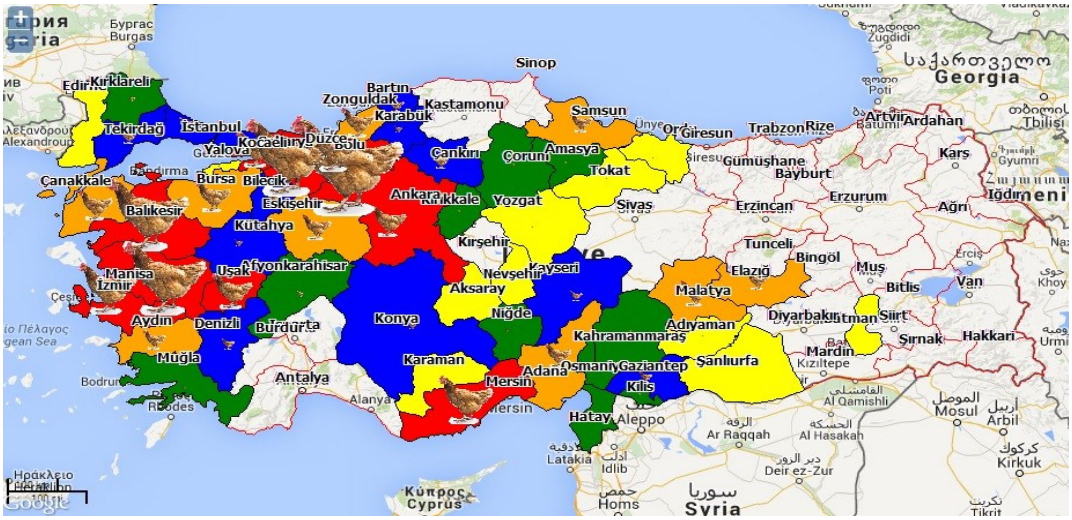

Figure 3.2. The population of chicken(broiler) over Turkey (BEPA Turkey biomass potential atlas, 2014).

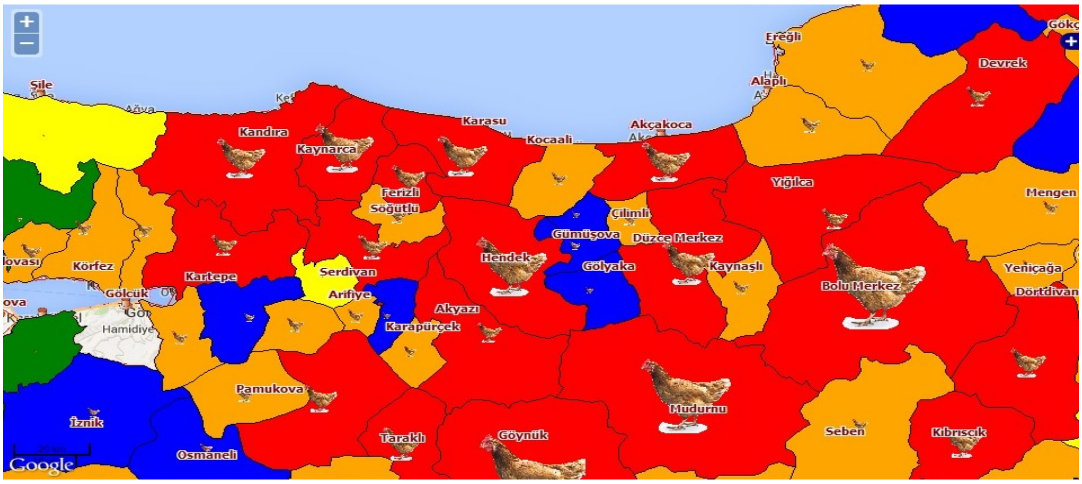

Figure 3.3. The population of chicken (broiler) around Kandıra is shown above (BEPA Turkey biomass potential atlas, 2014).

600 - 35.600 Chickens(broiler)	62
35.600 - 132.900 Chickens(broiler)	60
132.900 - 365.000 Chickens(broiler)	60
365.000 - 876.500 Chickens(broiler)	61
876.500 - 11.945.500 Chickens(broiler)	60
Number of Counties (not analyzed)	654

Figure 3.4. Number of chickens (broiler) – Number of counties with the selected colour (BEPA Turkey biomass potential atlas, 2014).

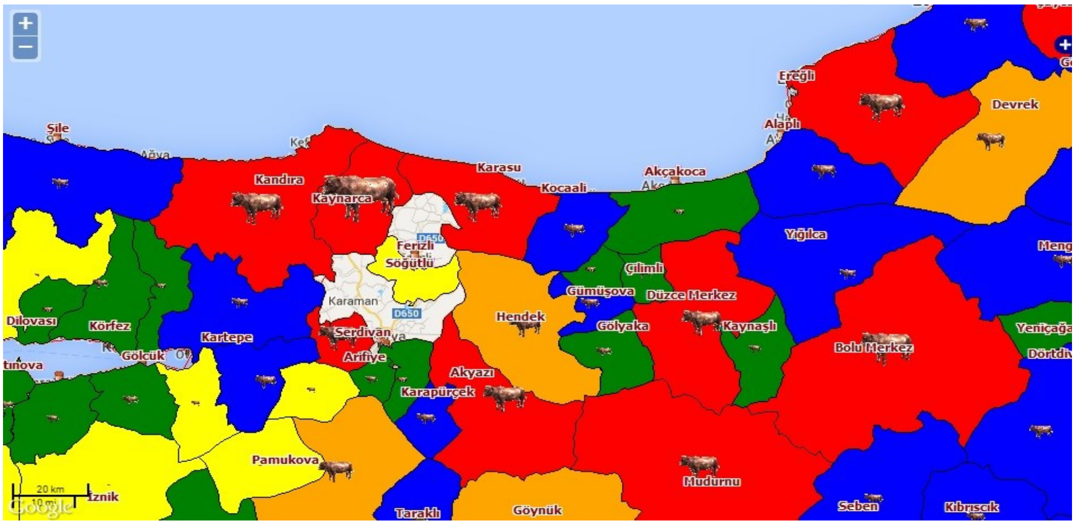

Figure 3.5. The population of cattles around Kandıra (BEPA Turkey biomass potential atlas, 2014).

7 - 961 Cattles	178
961 - 2.280 Cattles	175
2.280 - 4.685 Cattles	177
4.685 - 9.884 Cattles	177
9.884 - 95.870 Cattles	177
Number of counties (not analyzed)	73

Figure 3.6. Number of cattles – Number of counties with the selected colour (BEPA Turkey biomass potential atlas 2014).

Table 3.3. Biogas yield and wet manure for an animal.

Type of Manure	Wet manure (ton/year)	Biogas yield (m^3/year) for 1 ton manure
Cattle	3,6 tons / year	33 m^3 / year
Chicken (broiler)	0.022 tons / year	78 m^3 / year

Other raw material of our biogas process is cheese whey is a protein- and lactose-rich byproduct of the cheese industry. It is highly biodegradable with a very high organic content (up to 70 g COD/L), and low alkalinity (50 meq/L) (Mawson, 1994).

Cheese whey resulting from the production of cheese is the major polluting source in the waste water from the dairy industry. This situation leads to a significant food waste and without purification of this waste water cause environmental pollution.

The high organic content of cheese whey renders the application of conventional aerobic biological treatment costly, mainly due to the high price of oxygen supplementation. Anaerobic treatment requires no oxygen supplementation and generates a significant amount of energy in the form of methane gas (Ergurder et. al., 2001).

According to the old name with the Ministry of Environment and Forestry, while 100 kg of milk used in cheese production generates 90 kg of whey waste water.

In the calculations, the milk-cheese ratio was accepted as 7.5. Finally, the amount of milk used in cheese production 3,547,926 tons / year was found. Respectively amount of whey wastewater is 3,193,133 tons / year. Methane yield of whey wastewater was adopted as 23.4 L CH_4 / L .Calculated theoretical and technical whey waste water biogas potential values are given in Table 3.4 (Turk-German Biogas Project).

Table 3.4. Technical and theoretical biogas potential value of whey wastewater (Turk-German Biogas Project, 2011).

Parameters	Amount
Amount of milk for cheese production	3.547.926 tons/year
Cheese whey waste water	3.193.133 tons/year
Amount of Methane	74.719.311 m^3/year
Theoretical Biogas potential	2.7 PJ / Year
Technical Biogas potential	2.4 PJ / Year

Table 3.5. Location of Medium and large-sized milk factories (>50 000 L/Day) (Turk-German Biogas Project, 2011).

Regions	Units	Annual Production ('000 liter)	Percentages
Mediterrian	4	255.600	7,0
Marmara	22	2.134.800	58,1
Central Anatolia	16	541.800	14,7
Black Sea	4	118.800	3,2
Aegean	8	622.800	17,0
TOTAL	54	3.673.800	100.0

Official total milk production value is 11,717,080 mt for 2009.

It is clearly shown in table Marmara region is the biggest milk provider region of Turkey that Kandıra is well located county about supply of these raw materials. According to the laboratory analysis total solids of raw materials are shown in Table 3.6.

Table 3.6. Total solids ratio of wastes in pilot plant.

Waste type	Total solids (%)
Cattle Manure	% 8
Chicken (Broiler) Manure	% 60
Cheese Whey	% 5
Mixture of Wastes	% 12

The detention time at which 70% of the biogas production observed gives the most efficient detention time of the anaerobic digesters (Kishore et. al., 1987).

Process is tried on laboratory scale plant and detention time is adjusted for 38 days. Cattle and chicken (broiler) manure from farm and cheese whey are stored in primary storage tank. Dry matter rate is adjusted as %12.Proses performed on mesophilic conditions (30^0-40^0C). Fermentation duration is adjusted for 38 days. Biogas burned in Organic Rankine Cycle integrated co-generation system. Electricity and heat is used inside the plant. Remaining electrical and heat energy can transport and use in other places. Dry and liquid fertilizers are produced from digested waste. With the cover-up of the last storage tank % 5 more biogas production is assumed.

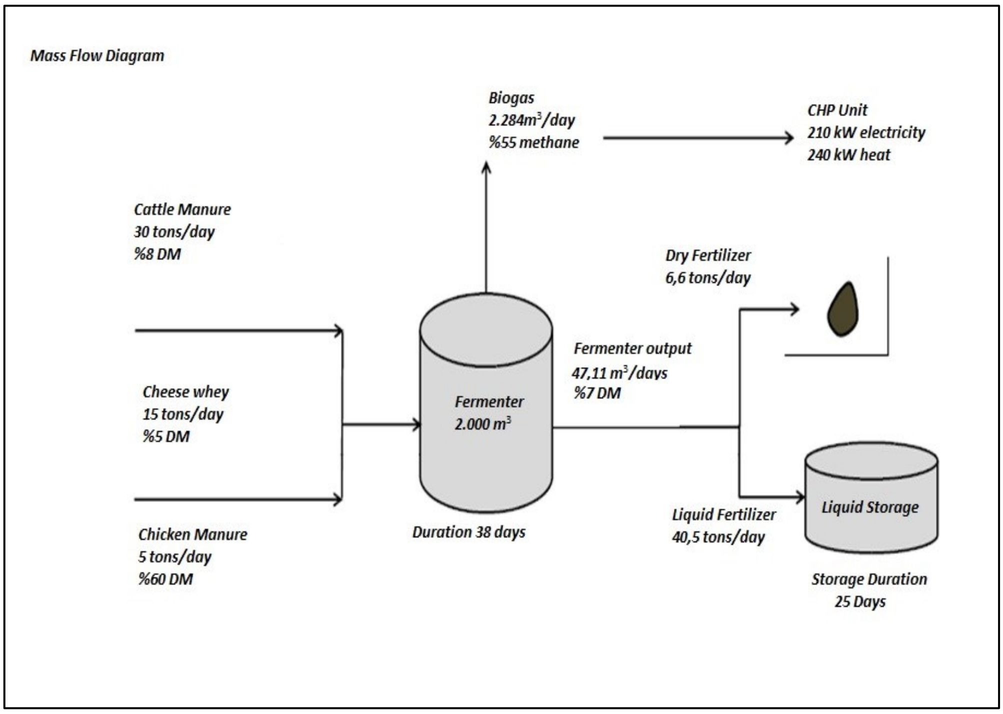

Figure 3.7. Mass flow diagram of Kandıra biogas plant.

Due to the process of pilot plant in Kandıra;
Waste (ton/day) x 330(day /year) = Waste (tons/ year)

- 9,900 Tons of cattle manure, 4.950 tons cheese whey, 1.650 tons cattle (broiler) manure are utilized per year.

- Greenhouse gas emissions of these raw materials are reduced ≥ %70 due to usage of methane as a fuel in cogeneration system.

- 2178 tons dry fertilizer and 13365 tons liquid fertilizer are produced, consequently 15543 tons of artificial fertilizer usage is avoided.

- Volatile solids reduced in wastes ≥ %40 due to 833.000 m^3/year biogas production by anaerobic digestion process.

- Odor nuisance from manures is reduced by AD process.

- The yearly electricity production is 1.839.600 Kwh equal to 666 households (4 members 2760 kwh/year electricity consumption) electricity demand.

- Chemical oxygen demand of wastes are reduced %40 by anaerobic process.

The potential for the contamination of natural waters by both non-pathogenic and pathogenic microorganisms is reduced by anaerobic digestion..

CHAPTER 4

LIFE CYCLE COSTING METHODOLOGY

The AD biogas plant in Kandıra is environmental friendly system that prevents pollution of organic wastes such as cattle manure, chicken manure and cheese whey. Therewithal we can produce electricity and heat energy with this system. So it has also economic benefits.

This thesis determines economic benefits of AD biogas plants. The project performs Life Cycle Costing methodology of the Pilot plant in Kandıra.

The LCC analysis takes the investment costs and costs in operation of all phases into account. In general, LCC yields present value of current and future expenditures for procurement of building and operating and maintaining the building through its life. As the operational costs make up the main part of the total costs over the whole lifetime of a building, the LCC comparison of different scenarios creates the necessary transparency for the decision-making process (Hunkeler et. al., 2008).

4.1. EXPENSES OF THE PILOT PLANT

4.1.1. Investment Costs

The design, construction and installation of the industrial biogas plant are the investment costs. Investment cost is calculated with the formula shown below;

Built-in capacity (kWh) x Investment expenditure (€ / kWh) = Investment Cost
210 x 4000 = 840.000

The main investment cost of the pilot plant will be 840.000 € including four main units which are;

- Primary Storage
- Anaerobic Digester
- Final Storage Tank
- 210 kW Organic Rankine cycle integrated Cogeneration Unit

Other components of biogas plant;

- Pumps
- Mixers
- Heating systems
- Pipes, valves and measuring instruments

4.1.2. Operational Costs

Personnel costs: are calculated based on three (3) shifts each with one operating personnel. There will be three (3) employees in total each with 1500 € / month salary including annual social security and other social services.

Personnel costs per year are calculated below;

3 x 1500 x 12 = 54.000 € / Year

Maintenance costs: Assumed as 3% of the equipment cost (Kaya et. al., 2009).

Maintenance costs per year are calculated below;

0.03 x 840.000 € = 25.200 € / Year

*Insurance and taxes c*osts: Assumed as 7.5% of the investment cost and assigned as overhead cost (Kaya et. al., 2009).

Insurance and taxes costs per year is calculated below

0.075 x 840.000 € = 63.000 € / Year

Transportation costs: The supply of the raw materials is assumed as 3 €/ton including the transportation cost (Kaya et. al., 2009).

(35 tons/day cattle manure + 5 tons/day cheese whey + 15 tons chicken (broiler) manure = 50 tons / day raw material

50x330 = 16.500 tons / year raw material

3 € x 16.500 = 49.500 € / Year

4.1.2. Incomes of the Pilot Plant

The following items will provide an income during the operation of the Pilot Plant:

Electricity sales: with a unit selling price of 0.094 € / kWh (Resmi Gazete, 2010).

Built-in Capacity x (-%20) x (working hours) x Electricity unit price

210 kW x (-%20) x 8.000 x 0.094 €/kWh = 126.336 € / Year

Profit from Carbon Trade (Green Certificate): with a unit selling price of 0,020 € / kWh (Kaya et. al., 2009).

210 kW x (-%5) x 8.000 x 0.020 € / kWh = 31.920 € / Year

Heat sales: with a unit selling price of 0.030 €/kWh (Kaya et. al., 2009).

240 kW x (-%20) x 8000 x 0.030 €/kWh = 46.080 € / Year

Organic fertilizer sales: with a unit selling price of 30 € / ton (Kaya et. al., 2009) 6,6 tons / day x 330 = 2.178 tons / year

30 € / ton x 2.178 = 65.340 € / Year

Incomes & Expenses parameters are shown below Table 4.1

Table 4.1. Incomes & Expenses parameters.

Incomes & Expenses parameters	**Total Cost**
Investment costs	840.000 € / Year
Expenses Costs	
Personnel Costs	54.000 € / Year
Maintenance costs	25.200 € / Year
Insurance and taxes costs	63.000 € / Year
Raw materials and Transportation costs	49.600 € / Year
Total Annual Expenses	**191.700 € / Year**
Income Fees	
Electricity sales	126.336 € / Year
Carbon Trade	31.920 € / Year
Heat sales	46.080 € / Year
Organic fertilizer sales	65.340 € / Year
Total Annual Incomes	**269.676 € / Year**
Total Annual Net Profit	**77.976 € / Year**
Payback Period	**840.000 / 77.976 = 10.5 years**

CHAPTER 5

CONCLUSIONS

This thesis aims to make the environmental and economic assessment for pilot plant in Kandıra that consists of an AD plant and organic Rankine cycle integrated cogeneration system, where the organic wastes such as; cattle manure, cheese whey, broiler chicken manure are used as raw materials.

The potential environmental impacts of these wastes that are anaerobically digested in the pilot plant are evaluated with the implementation of Life Cycle Assessment (LCA); whereas the economical evaluation of the plant is carried out with Life Cycle Costing (LCC).

Functional unit of this study is %10 more biogas production with co-fermentation of cattle manure, cheese whey, chicken (broiler) manure mixture. When only the chicken (broiler) manure chosen as raw material, it cause poisoning inside the fermenter. Whey cheese has a low pH and it is rapidly hydrolyzed. Cattle manure has relatively low biogas production capacity but has high buffering properties. This plant aims %10 more biogas production is with co-fermentation of these 3 wastes.

The results of the LCA study shows that 9.900 Tons / year of cattle manure, 4.950 tons / year cheese whey, 1.650 tons / year chicken (broiler) manure are utilized and the pollution potential of these wastes are prevented. By the utilization of these wastes, 2.178 Tons / year dry fertilizer and 13.365 tons / year liquid fertilizer are produced, consequently 15.543 tons of artificial fertilizer usage is avoided, odor nuisance from manures is reduced by AD process, the potential for the contamination of natural waters by both non-pathogenic and pathogenic microorganisms is reduced by anaerobic digestion, chemical oxygen demand and volatile solids of wastes are reduced %40 by anaerobic process.

The results of the LCC study shows that yearly electricity production is 1.839.600 Kwh equal to 666 households (4 members 2760 kwh/year electricity consumption) electricity demand. This plant ensures economic incomes such as 126.336 € / Year from Electricity sales, 31.920 € / Year from Carbon Trade, 46.080 € / Year from Heat sales, 65.340 € / Year from Organic fertilizer sales.

The investment cost, operational cost and income of the Pilot Plant show that the payback period of the Pilot Plant will be 10.5 years.

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BIOGRAPHY

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