# Environmental Efficiency Evaluation Based on Waste Reduction for a Chemical Production Company: An Application of Data Envelopment Analysis

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# ABSTRACT

Data envelopment analysis technique proposed by Charnes, Cooper and Rhodes in 1978, was used in this thesis in analyzing the efficiency of thirty two decision making units of the chemical production company, simple relation of output-to-input ratio couldn't be used because of the several number of decision making units. The thesis focus on how to minimize the environmental hazard caused by industries without affecting the production capacity of the industries, the data was analyzed using CCR model as the methodology used which is one of data envelopment analysis technique. There were four Decision making units (DMU6 = June 2017, DMU7 = July 2017, DMU14 = February 2018 and DMU25= January 2018) found to be optimal which meant the minimal waste disposal found to be in the four decision making units, and such units were found to be the benchmarks for the rest of the DMUs in order to minimize waste disposal, and can also be the benchmarks to consider at DMUs in the future production process in minimizing the amount of waste disposes to the environment which would proportionally minimizes the effect of Climate change, and also minimizes energy consumption at industries. Each DMU used served as a month in a particular year.

**Keywords:** Data Envelopment Analysis, Efficiency Evaluation, Environmental Hazard

# ÖZ

Veri Zarf Analizi, ilk defa 1978’de Charnes, Cooper ve Rhodes tarafından bir kimyasal firmanın 32 karar verme ünitesinde kullanılmıştır. Sade girdi çıktı ilişkisi kullanılmamıştı çünkü firmada birçok karar verme ünitesi mevcuttu.

Bu tezin amacı üretimi düşürmeden endüstrilerin yarattığı çevresel tehlikeleri en aza indirmektir Bu bilgiler Veri Zarf Analizini bir tekniği olan CCR model ile analiz edilmiştir Bu çalışmada 4 karar verme unitesi (DMU6 DMU 7 DMU 14 DMU 25) bulunmaktadır Bunlar atık imhası için en en uygun sonuçlardır. Aynı zamanda bu 4 unite gelecekteki atık imhası için enerji tüketimini azaltmak ve çevresel tehlikeleri minimize etmek için kıyaslama olarakta kullanılabilir.

**Anahtar Kelimeler:** Veri Topmlama Analizi, Verimlilik Değerlendirmesi, Çevresel Tehlike

# DEDICATION

I would like to dedicate this research work of mine to my late father Mr. Tukur H. Gwarzo, whose dream was to see me complete this masters of Science degree program. Unfortunately, he would not be home when i get back to my country. May his gentle soul Rest in Peace.

# ACKNOWLEDGEMENT

I would like to show my gratitude and appreciation to my great supervisor Assist. Prof. Dr. Sahand Daneshvar. For his encouragement, support, guidance and advice towards my research from the very early stage to the end of this thesis. His endurance on responding to my questions even after his official working hours would not be forgotten. And also his ideas shared and time spent on me in teaching me the idea behind this research work and the concept behind the methodology used is memorable.

The effort of the production Manager for Dagli Cosmetics and detergent company in person of Mr. Adem Küçük must be appreciated and memorable, towards his support on making sure that i understand the whole production process and the variety of products processed in the company, and such gave me a clear knowledge on the kind of data to use with the approval of my supervisor. Without the managers’ support, collecting some data would have been impossible for me to get because some data were not directly recoded.

I would like to appreciate the effort, concern and the time spent on my research defense by the jury members committee in persons of; Assoc. Prof. Dr. Gokhan Izbirak, Assist. Prof. Dr. Sahand Daneshvar and Assit. Prof Dr. Mohammad Ali Mosaberpanah In making sure that I write the necessary points and be able to defend all my points made in my research.

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# Chapter 1

# INTRODUCTION

In this introductory part of the thesis, a brief description of the problems caused by harmful waste disposal to the environment, a description of controlling such problems, an introduction of the methodology followed in tackling such problems, and also a description of the structure of the thesis is discussed.

## 1.1 Problem description

In this age, as a result of rapid growth of world population and technological development in the world which results massive number of processing industries with massive production capacity to satisfy people's demand, such production also results in undesirable products (negative products) mostly in the form of waste that were later disposes out from industries to the environment, and some are disposes out from markets and houses to the environment. Some of the waste disposes to the environment includes; washed chemicals from chemical industries, carbon dioxide emission from industries such as cement industry, Nylons and plastics disposal from plastic industries and markets, metals from electronics disposal and industries, and other materials releases from houses such as used remote batteries and other toxic materials, from markets which includes several category of waste. Such waste disposal to the environment became rampant in this 21st century and results in severe environmental damage by contaminating the soil, water and air. This environmental contamination leads to environmental Hazard which results human health issues and also results in climate change. Some waste like, Lead metals from electronics and industries waste causes damage to central and peripheral nervous systems, kidney, blood system and affect brain development of children. Plastics and Nylons waste produce dioxin when burning which causes reproductive problems and damages the human immune system. Discharge of chemicals like Hydrocarbon into water, acidifies the water destroying fishes and other living organism, which may cause food shortages.

## 1.2 Control Description

Multiple measures were suggested by researchers in order to reduce this environmental hazard, such as; government should create awareness to people on the effect of disposing waste to the environment, Categorizing each component for testing and Separating harmful materials from the waste and making partnership with private companies to receive the waste that they consider as their raw materials and earn income in return, this will increase the efficiency of both industries (Gupta, 2012). In this thesis the researcher` also made some suggestions based on the results obtained in chapter 5 to ensure the minimization of harmful waste disposal to the environment.

Government has to use their power as a government to make some control of harmful waste disposal. This includes; the collaboration with different researchers to know the potential threats of each of the kind of waste disposed to the environment, provision of awareness on the effect of harmful wastes to human body and their environment, imposing policy to industrial body on the tolerance amount of waste that they can dispose and such policy will force the industries to restructure their production process to deal with the waste disposal. A compulsory course related to the effect of environmental hazard should be provided to Schools.

## 1.3 methodology description

In this study, considering a chemical company that produces cosmetics and detergent as its fundamental output. However, every production process also has negative outputs that their disposal is harmful to the environment, to perform a proper and holistic analysis, those negative outputs must be integrated in the efficiency analysis of the company. Therefore, Environmental Efficiency of the chemical company can be evaluated using Data envelopment analysis (DEA) to decrease the Environmental Hazard caused by the process industry and energy consumption of the industry and keeping its production amount in the desired level, when considering that negative output in the efficiency evaluation of the industry. One of the most basic technique of this Data envelopment analysis called CCR model was used to analyze the industrial data in order to evaluate the efficiency of the factory in relation to its negative products disposal, the higher value of the efficiency received shows how small the amount of the waste disposed and the lower the efficiency value means higher waste disposal, this inverse proportionality relationship between the efficiency and waste amount is due to the inverse of the waste amount used as output, therefore by the taking the inverse of higher value of waste amount would result to lower output value which will caused low efficiency value and also taking the inverse of lower waste amount would result to higher output value which would result to higher efficiency value of the analyzed decision making unit (DMU). Monthly production data is considered as the decision making unit (each month is considered as one unit). The data envelopment analysis as the technique used was initially proposed by Charnes, Cooper and Rhodes in 1978, which can be used to choose the best decision making unit of the evaluated DMUs of the industry.

## 1.4 Structure of the thesis

Previous research relevant to this work were reviewed to justify this research work in chapter two of this thesis that reviewed the findings made by researchers on evaluating the efficiency of industries considering its waste disposal, ways follows to minimize such industrial waste disposal, environmental effect of such waste disposal and how to minimizes the effect of such waste disposal were all reviewed in the first part of chapter two,  review on the concept of data envelopment analysis which is the methodology applied in this research was also discussed in the second part of chapter two, and also the industrial application of the methodology used was reviewed in the last part of chapter two. Chapter three explains all the procedure followed in conducting this research work, which used the concept of one of the technique in data envelopment analysis called CCR model which was solved using PIM-DEA software. The industrial data analyzed, and the procedure followed in receiving and quantifying the data was shown in chapter four. The results received using the PIM-DEA software was shown and the meaning of the results were also discussed in chapter five. And the conclusion and recommendation were explained in chapter six. Then the referenced used in the research followed after the sixth chapter and lastly the appendix content, which contained the relevant pictures of the industrial waste used and some of the data information used. The figure 1.1 below summarized the whole thesis structure.

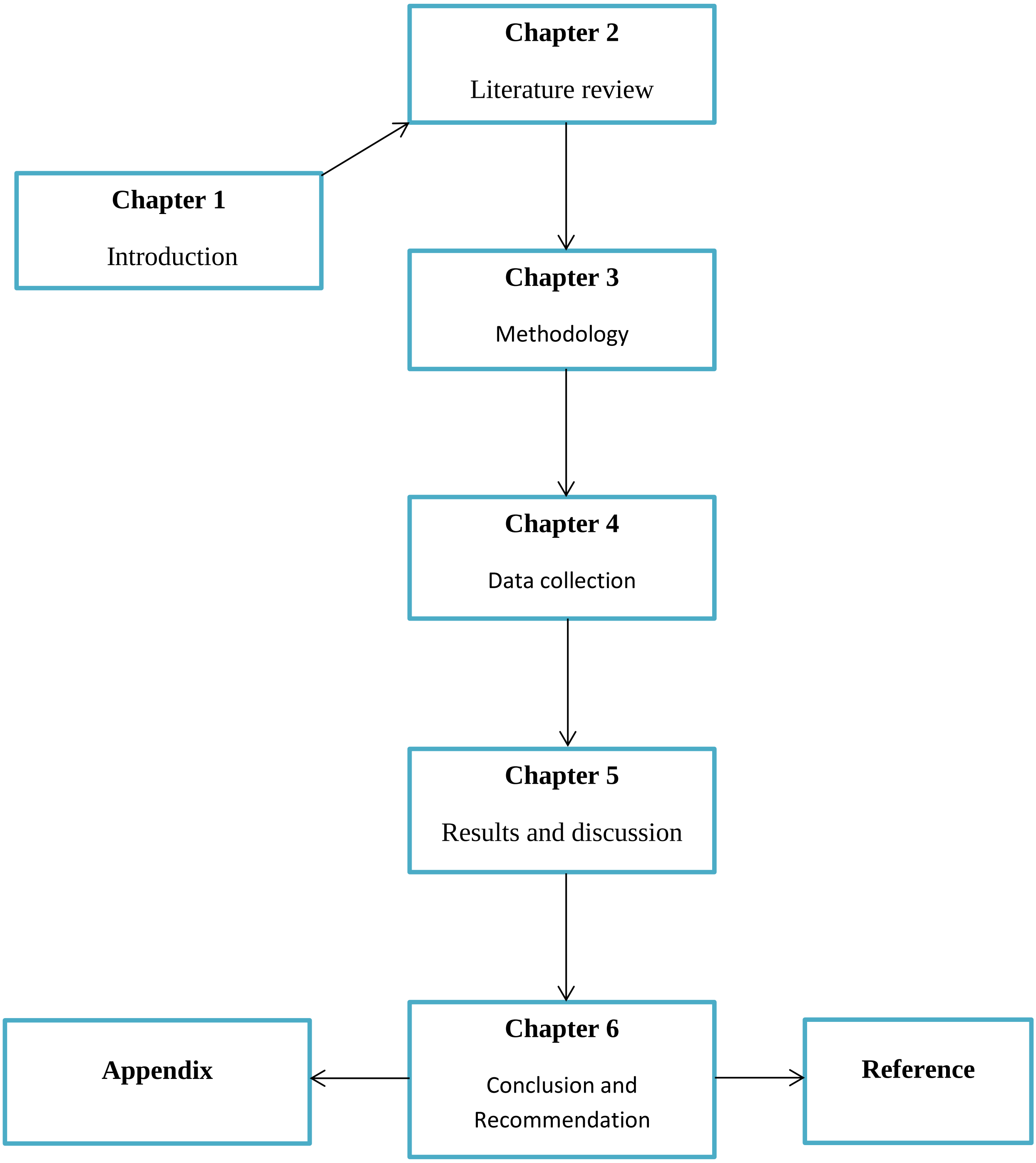


Figure 1.1: Structure of the thesis

# Chapter 2

# LITERATURE REVIEW

Due to the rapid growth of population and technological development in 21ts century, the number of industries is rapidly growing to satisfy customers' demand, which exponentially increases the risk of environmental hazard. Below is a review of studies on Environmental Hazards (such as; its causes, problems and control) and data envelopment analysis and its applications to industries.

## 2.1 Waste and Environment Hazard

Waste can be defined as anything that is disposed from its source or by its holder or user without the intention of using it again, to the environment (Sarkis et al., 2011). A substance either in the form of Solid, liquid or gas is said to be a waste when dispose out from its region to environment (Panda, 2013). Waste in terms of electronic devices was defined by Gupta (2014), as disposed electrical devices to the environment.

Thus, Waste can be understood as any substance that is discarded from its region or disposing unwanted materials. For example; trash from houses, release of chemicals from industries or disposal of garbage from Markets. Some wastes are beneficial to human life when released to the environment (example, agricultural waste add nutrients to the soil) while others, are hazardous causing environmental hazard. Such hazardous substances have negative impact on human life when disposed.

The title “hazardous waste” was originated by Environmental protection Agency (EPA) in United State of America, there is no single globally accepted definition of hazardous waste, defining a substance as hazardous waste depends on a country’s categorization of waste, different countries have different categorization of what to be considered as hazardous waste. This could either be by determining the properties of the waste and comparing it with hazardous materials or by examining the waste for what they consider as hazardous (Cheng et al., 2018).

## 2.2 Sources and classes of waste

Waste can mainly be classified in to Solid-waste, liquid-waste or Gaseous-waste (Nathanson, 2016). And each one of these classes can further be categorized in to Hazardous and Non-hazardous substances. Wastes’ sources can be categorized in to Industrial wastes’ source, domestic wastes’ source, medical wastes’ source and electronic wastes’ source (Panda, 2013).

Hammer (2003), indicate other sources of wastes from;

- Construction industries
- Energy generation firm
- Agricultural industries
- Waste from Abattoir
- Water treatment plant
- Markets
- Hospitals

### 2.2.1 Classes of Solid waste

Hammer (2003) mentioned some composition of solid waste, which constitutes of;

- Biodegradable organic substances;
- Poisonous substances;
- Metallic materials;
- Non-biodegradable substances

Biodegradable substances (such as; Plants and animals) are substances that can easily be decomposed by the action of microorganisms, while Non-biodegradable substances (such as; plastics, glasses) cannot easily be decomposed and remain for over long period of time which causes hazard to the environment (Zheng, 2010).

### 2.2.2 Classes of Hazardous liquid and gas waste

According to Vignesh and Barik (2019), Liquid hazardous waste can be categorized based on its Corrosiveness (includes; Concentrated form of acid, sodium hypochlorite), Non corrosive nature but causes environmental hazard (example; vegetable oil from food industries), Flammability (ability for a chemical to catch fire. Example; petroleum,), and gaseous form of hazard can be classified as explosive and Non explosive hazard. The explosive gases are the gases that can easily catch fire and lead to explosion when leaked with air and in the of ignition source (example; propane gas). And the Non explosive gases are carbon monoxide and Hydrogen sulfide (Lambrini et al., 2018).

## 2.3 Growing of Environmental hazard and its effects

Due to the fast development of industrialization, Agriculture, urbanization and our natural resources in the 21st century. There has been a rapid growth of Waste to our environment, ranging from harmless waste to highly hazardous waste. When hazardous waste is not properly handled or managed, it may endanger human life and pose a threat to the environment. As a result, of such rapid growth of waste nowadays, managing waste must be put into consideration i.e. the disposal, handling, transporting and recycling of this hazardous form of waste must be carefully considered (Cheng et al., 2018).

E-waste is one of the fastest growing waste streams in the world. In developed countries, on average, it equals 1% of the total solid waste. The increasing “market penetration” in developing countries, “replacement market” in developed countries and “high obsolescence rate”, make e-waste one of the fastest waste streams. It includes items such as televisions (TV), computers, Liquid Crystal Display (LCD), plasma panels, printing-scanning devices, mobile phones as well as a wide range of household, medical and industrial equipment which are simply discarded as new technologies become available. Huge quantities of these wastes are discarded every year. These wastes contain toxic and carcinogenic compounds can pose high risk to the environment, computer lead and cadmium are used in circuit boards, lead oxide and cadmium in cathode ray tube monitors, mercury in switches and flat screen monitors, cadmium in computer, polychlorinated biphenyls in older capacitors, transformers and batteries. Presently, Indians use about 14 million PCs, 16 million mobile phones and 80 million televisions. Therefore, there is a pressing need to address e-waste management particularly in developing countries like ours. The presence of valuable recyclable components, in electronic wastes, attracts informal and unorganized sectors towards it but the unsafe and environmentally risky practices adopted by them pose great risks to health and environment (Panda, 2013).

Based on the report received by United Nations Environment program (UNEP) on the massive growing of waste from electrical appliances, which exponentially increases the Environmental hazard. In the year 2020, electric waste from disposed refrigerators will increase by 300 percent, disposable mobile phones will increase by 1800 percent while the rate of discarding old computers will be three times higher when measured with 2007 record. By considering this rapid growing of electrical waste, all the disposed waste from developed countries like America, United kingdom and japan can be sent to developing countries such as; African countries, India and China (Gupta, 2012).

Researchers from different part of the world conducted studies on the effect of disposing hazardous waste to environment on human health, they found out that untreated discharging of some chemicals, example; Lead, Mercury, cyanide and some chlorinated compounds are very toxic which can cause serious diseases like; cancer, infertility, brain damage and many more, that can lead to death. Some researchers hypothesized that the rampant infection of cancer is due to the releases of these hazardous waste from our industries (Panda, 2013).

Table 2.1: Problems caused by some solid hazardous waste (Gupta, 2012).

| **Sources** | **components** | **Effect** |
|---|---|---|
| Relay and Circuit boards | Mercury | causes a serious brain damage, and skin disorders |
| Semiconductors and resistors of electronic devices | Cadmium | Damages kidney and liver<br>Damages Neural part of brain<br>Affects unborn babies in the stomach |
| Electronic devices like televisions, and computers | Lead | Affects the development of brain for children<br>Kills central nervous system |
| Steel plates | Hexavalent chromium | Damages DNA and causes Asthmatic |
| Rubber bottles and cables | Plastics | Affects human reproductive system and damages human immune system |
| In the front panel of cathode ray tubes | Barium | Causes liver, kidney and heart damage, and increase human blood pressure |
| Electronic devices motherboards | Beryllium | Skin diseases and lung cancer |
| Mobile phones and computer covers | Brominated Flamer | Affects hormones responsible for developing sexual function, tissue function, reproduction, sleep and mood in human |

## 2.4 Waste management and control

Panda (2013), suggested a way that will reduce environmental hazard and increase our economy, by making good use of our industries efficiently in converting any form of waste particle into a number of useful forms. Some lucrative companies utilize their waste in the production of new products, such processes minimizes waste disposal and reduces environmental hazard (Plambeck, 2012).

Another strategy for waste prevention was developed by considering some optimization and heuristic methods that will improve in the management practices to deal with solid waste (Cabanelas et al., 2013). The main aim of waste management policy is to prevent waste (Gentil et al., 2011). Gupta (1995) suggested that, any method can be considered as long as it can prevent waste formation.

Some examples that will significantly reduce hazardous waste are listed below (Wilts et al., 2013).

- At home, we should minimize where possible the use of disposable items like baby napkins, nylons, women pads and other disposable items. And also separate different forms of waste like plastic/nylons, cartons and other disposable materials for easy separation in the recycling process. Consider buying some items like food in bulk amount, to avoid accumulating of many packing bags to avoid unnecessary waste.
- Government should discourage the use of nylon bags for serving customers in the markets, alternative source of packaging should be provided like a basket that a customer can always be carrying to the market which can be used for a long period of time.

Another strategy was developed by Gentil et al., (2011), that at the end of production in an industry, the end products that are considered as waste will be recycled, which is shown in a block diagram below;

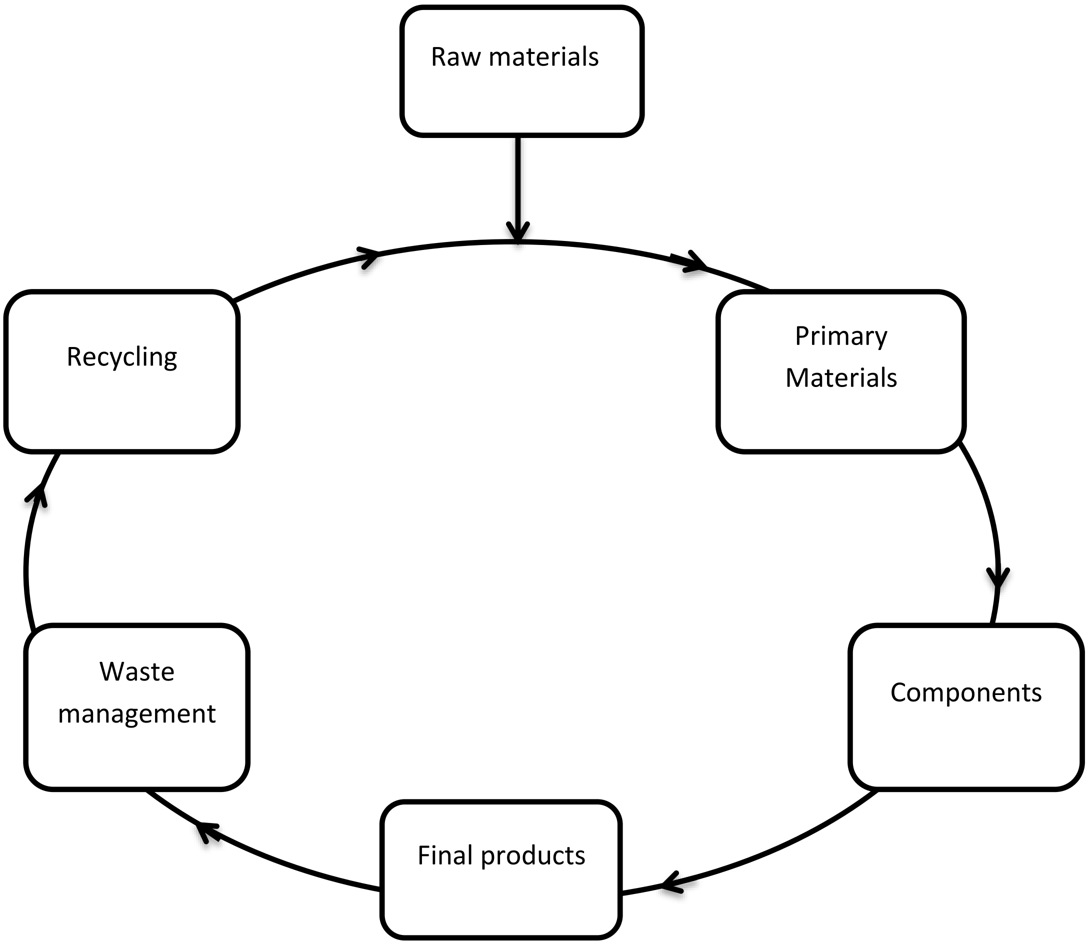


Figure 2.1: Assignment of target levels (Gentil et al., 2011)

Apart from the recycling process considered as hazardous waste management control, there is another treatment technique suggested by Nathanson (2016).

Table 2.2: Waste management

| | **Control** | Control Process | Potential threat |
|---|---|---|---|
| Treatment | Use of chemicals | Precipitation, oxidation, reduction and neutralization | |
| | Action of Thermal | Some waste get detoxified or even been destroyed when exposed to high temperature | But causes air pollution |
| | Biological method | **Land farming:** mostly organic waste, the waste mixed with soil and add some microbes to feed on the waste. **Bioremediation:** developing some genetically engineered bacteria on the waste site, then adding microbes to stabilize the contaminated site | If microbes were not added to the soil site after the action of the genetically engineered bacteria, food crops may not grow on the site. |
| | Physical method | Mostly a solid waste; Filtration, Sedimentation, Flotation and evaporation. Such techniques reduces the amount of waste | |

## 2.5 Toxic waste from Chemical Industry and control

Apart from the useful products produced by chemical plants, some harmful substances such as; carbon dioxide which is the major potential source of global warming, and Unburned hydrocarbon, Carbon monoxide, oxides of nitrogen, oxides of sulfur are released which have severe effect on human health. But some measures are considered to reduce the wastes' toxicity, such as; by considering the use of renewable energy sources for power source which prevents the releases of carbon dioxide and other toxic gasses from power generators. Among the renewable sources of energy (Solar, Wind, Biomass, hydroelectric, geothermal), Biomass source is the cheapest and most reliable renewable energy. Biodiesel (biomass) is one of the most important source of renewable energy which is currently produces in abundance around the world, but its massive production generates large amount of by-products which is also a disaster to environment (Vignesh & Barik year).

## 2.6 DEA and its Standard models

(Gobbi et al.,2019) in a research on a mathematical program named data envelopment analysis(DEA), found out that DEA was initially designed to evaluate the efficiency of a school teaching process, and some models were added later in the designed DEA (Mahdiloo et al., 2018; Kao, 2014). Apart from evaluating the teaching process, Health entities like Hospitals, Transportation entities like airports, Industries entity, energy generation plant like power plant, and Business sectors can use the concept of DEA to evaluate and compare the efficiency of each decision making unit of a sector, for example; comparing the efficiency of all general hospitals in Cyprus (Yeh et al.,2016; Zhou et al.,2016). Guerreiro (2006), Peixoto (2013) and Ehrgott et al., (2018) defined Data Envelopment Analysis as a Comparative Linear programming technique that quantify the relative efficiency and performance of a decision making unit of an entity, and the values of this efficiency ranges from 0 to 1, in which the value 1 efficiency means 100% and the 1 value classified as Efficiency frontier, and the ratio of raw materials(input) to the final products(Output) defined the efficiency (Eficiency = Input/Output) (Guerreiro, 2006;

Peixoto, 2013; Ehrgott et al., 2018). The most important and independent DEA model popularly known as CCR model, was developed and named by Charnes, Cooper and Rhodes in the year 1978, This model can also be called a Constant Return to Scale (CRS) because of its proportional responds to final products/Outcome (Output) when raw materials/Resources (Input) were altered. The other model called BCC model also known as VRS (Variable Returns to scale) due to its unproportional varying on its output, properties, or efficiency frontier and input (Sousa, 2010; Menegazzo, 2013; Peixoto, 2013). Different decision making unit's efficiency can be compered and analyzed by individuals which will give room for the efficiency optimization of the desired decision making unit.

According to the research journal made by Ataei and Naserian (2015) in the field of data envelopment analysis, they discussed that DEA is a linear programming technique uses in the efficiency evaluation of decision making unit. The efficiency of a production unit was measured and analyzed by Farrell 3 in the year 1957, using this same technique and considered one input and one output in the analysis (Shokrollah et al., 2005).

Minuci, Neto and Hall (2019) also discussed in their journal that data envelopment analysis as a mathematical programming tool that determine the best decision making unit (the unit with the maiximum amount of outcome when compared with other units) based on the available resources used in an industry or any other sector (Ruggiero, 2001). DEA technique has been used to examine or asses our schools education system right from elementary, secondary, up to the University level in our country (Obadi´ c and Aristovnik, 2011; Aristovnik, 2012; Miningou and Vierstraete, 2013; Calhoun and Hall, 2014; Nazarko and Šaparauskas, 2014; Huguenin, 2015; Lauro et al., 2016; Munoz and Queupil, 2016) .

In a research by Ataei and Naserian (2015), discussed that in order to increase higher efficiency in a process plant, Health sectors or any organization, the Output quantity needs to be increased and the input amount has to be decreased to an appropriate amount. Generally, increasing efficiency in any decision making unit is either by lowering the input amount or by increasing the output amount, and the technique used is divided in to two categories namely; parametric and nonparametric technique. The parametric method involves considering a specific form for the production function and then statistical estimation of unknown coefficient of parameter function. While there is no any form consideration in non-parametric technique (Mehregan, 2004).

## 2.7 Environmental and Chemical Industrial Application of Data Envelopment Analysis

Data envelopment analysis is used to evaluate the efficiency of an industry and has a wide area of application, such as Food industries, Banking industries, Mining Industries, Transportation industries, Construction Industries and chemical industries.

Biodiesel is one of the renewable fuels that substitute the use of diesel oil in our industries and our equipment. This biodiesel can be processed by esterification of waste vegetable oil using Strontium and Zirconium dioxide as catalyst. Here, a modified data envelopment analysis (MDEA) in hybrid with Neural network proposed for the experimental design of multi-response problems, and compared with another statistical technique known as Response surface methodology (RSM), to optimize the yield of Fatty Acid Methyl Ester in processing the biodiesel. The following Variables were considered as the decision making variables such as; methanol to oil molar ration, catalyst loading, reaction temperature, reaction time on the Ester yield, and finally the free fatty acid.in which the Free fatty acid conversion was calculated using the modified data envelopment analysis. It was concluded that the parameter setting using the "Modified Data Envelopment Analysis" technique is more accurate and reliable than using the "Response Surface Methodology" with a percentage of predicted Ester yield of MDEA and RSM at 5% and 14% respectively. And the conversion percentage error of 3% for MDEA and 19% for RSM. (Saeidi et al., 2016).

In a research made by Recarrdi et al. (2012), on the efficiency of high energetic and carbon dioxide ($CO_2$) emission from cement industries in 21$^{st}$ century. Due to the toxicity of this $CO_2$ in our environment, effort must be made to reduce its emission and improve energy efficiency in order to the tackle problems encountered by climate change which is a major concern to environmental regulatory bodies. A standard data envelopment analysis and directional distance function technique were compared in evaluating the efficiency of cement sector with the $CO_2$ emission and also without the $CO_2$ emission. Cement production process was analyzed and then focused on the main cement industries' by-product named "Clinker" that is responsible for the emission of carbon dioxide. It was concluded that the undesirable factors (the carbon dioxide) has impact on the efficiency level together with developing technologies and utilizing some alternative fuels, and raw materials in cement and clinker industry (Recarrdi et al., 2012).

The industrial release of carbon dioxide gas to the atmosphere causes a lot of damage to human life, the gas is one of the greenhouse gas that pollutes our environment and that lead to so many diseases in human (example; respiratory disease) and also effect climate change. Trapping and utilization of such gas could be one of the strategies that reduces the greenhouse gas emission and also increase the profitability of the industries that stored the gas. Storing the carbon dioxide and using fossil fuel as a source of energy for power plants and other industries could help in minimizing the carbon dioxide emission. In this effort on minimizing the spread of carbon dioxide to surrounding, Data envelopment analysis was used in hybrid with Analytic Hierarchy Process to determine and chose the most efficient carbon dioxide utilization technique and storage option (Tapia et al., 2017).

Data envelopment analysis (DEA) together with Life Cycle Assessment (LCA) were the techniques used to estimate the environmental impact efficiency of twenty Natural gas combined cycle (NGCC) power plants located in Spain between the years 2010 to 2015.the steps involved the calculation of environmental impact using "life cycle assessment" and then estimating the environmental impact efficiency using "Data envelopment analysis" It was concluded that, only one out of the analyzed twenty natural gas combined cycle (NGCC) found to be environmentally efficient, the year with the highest efficiency found to be 2011 with 95% environmental impact efficiency. The relationship between the optimum working hours and high environmental efficiency was observed (Martin-Gambo et al., 2017).

# Chapter 3

# METHODOLOGY

Data envelopment analysis as discussed earlier in chapter two of this thesis, is a method, technique, or approach designed by Charnes, Cooper and Rhodes in the year 1978, used to analyze, evaluate or determine the efficiency of an entity called decision making unit. Particular number of inputs to achieve certain amount of outputs is considered in this decision making unit, the efficiency evaluation of processing the output produced in that decision making unit can be determine and also be compared with the other decision making unit using the data envelopment analysis. There are two fundamental models commonly used in the efficiency evaluation using DEA, named CCR model and BCC model. CCR model would be used in this research paper.

Here are some important parameters that need to be understood;

$\theta =$ Efficiency

$m = Number\ of\ inputs\ used\ in\ each\ decision\ making\ units (DMUs)$

$s = Number\ of\ Outputs\ produced\ in\ each\ Decision\ making\ units (DMUs)$

$u_r = Output\ weight\ \ (r = 1, 2, 3 \dots s)$

$v_i = Input\ weight\ \ (i =$ 1, 2, 3….m)

$y_{ro} =$ Amount of output $r$ produced by the observed $DMU_o$

$x_{io} =$ Amount of input $i$ used by the observed $DMU_o$

$y_{rj}$ =Amount of output $i$ produced by $DMU_j$

$x_{ij}$ = Amount of input $i$ used $DMU_j$

$n = Number\ of\ decision\ making\ units\ (DMUs)$

$DMU_j \quad j = 1,2,3 \dots n$

$DMU_o \quad is\ the\ desierd\ DMU\ or\ DMU\ being\ evaluated, where\ o\ ranges\ from\ 1\ to\ n$

## 3.1 Efficiency

The main concern of any businesses, schools, organizations, or industries is how efficient their system is, any sector can only keep running its activity in profit bases. So, evaluating how efficient an entity is become necessary, if not an entity can only realizes how inefficient its productivity is when severe damaged is done in the sector, which might lead to the destruction of that entity. For example, in a bread producing company where all the raw materials, packaging materials, processing equipment and production premises must be purchased, and also workers' salaries and energy consumption must be paid and any other expense, and the final product (bread) selling price must be compared with all the cost paid in processing the product to know how efficient the production is. If the product(s) selling prices is higher than the paid cost then it can be considered efficient (in terms of profitability) and the degree of efficiency can be determined. But if the paid cost is higher than the selling cost, then its considered as in-efficient, and the degree of its in-efficiency can be determined. In-efficient decision making unit can be upgraded to more efficient and the efficient ones can still be upgraded to the most efficient. Efficiency of an entity can be increased either by minimizing the input amount (input oriented DMUs) or by increasing the output amount (Output oriented DMUs)

Efficiency can be evaluated as the ratio of output to input amount. The efficiency of single input- single output decision making unit can easily be evaluated using the above definition. The mathematical representation of the definition represented below, and also the single input- single output diagrammatically represented below;

$$Efficiency = \frac{Output}{Input} \tag{3.1}$$

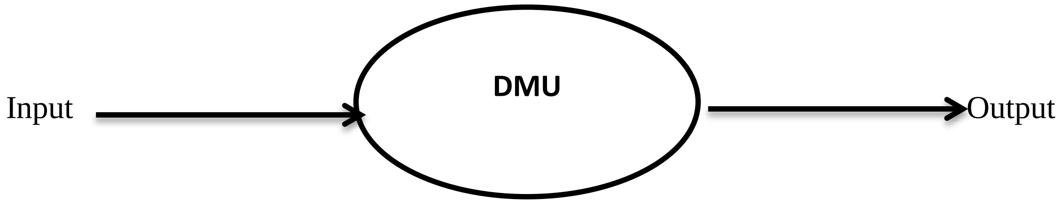


Figure 3.1: Single input-single output

In the case of multiple input and output, the equation (3.1) above cannot be used to calculate the efficiency of unit, CCR is a suitable programming technique that can measure the efficiency of such multiple input-output DMUs. Figure (3.2) below show the multiple inputs and outputs of a homogeneous decision making units.

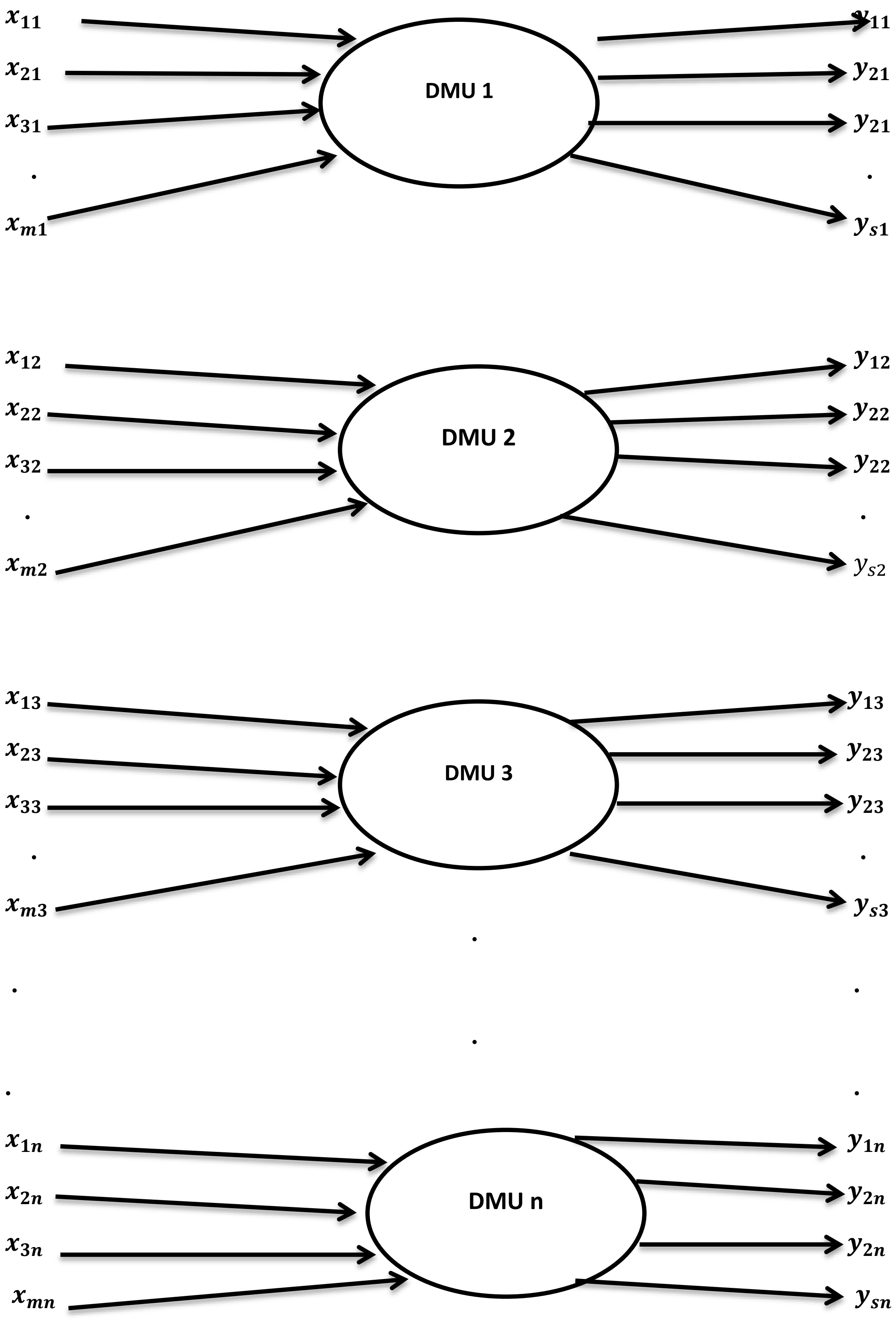


Figure 3.2: Multiple input- output of homogeneous decision making units

## 3.2 CCR model

The following programming model called CCR model, evaluates the efficiency of $DMU_o$ using input and output weights. The constraint (3.2) showed one as its maximum limit value that the ratio between virtual outputs ($u_r$) to virtual inputs ($v_i$) can reach in every decision making unit. The objective function in (3.1) determine the maximum ratio of Output to Input at the evaluating decision making unit ($DMU_o$), equation (3.3) and (3,4) are the non-negativity constraints of virtual inputs and virtual outputs respectively. The model below is the fractional program ($FP_o$) of the CCR model.

$$\max \theta = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{3.1}$$

$$subject\ to: \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad j = 1 \dots n \tag{3.2}$$

$$v_i \geq 0 \qquad i = 1 \dots m \tag{3.3}$$

$$u_r \geq 0 \qquad r = 1 \dots s \tag{3.4}$$

The following model is the linear form of the above fractional model, called linear program ($LP_o$). Both the fractional and linear programs of the CCR model are equivalent but the linear form model is easier to use. Efficiency of a decision making unit in DEA can be increased by either minimizing the input amount (using input-oriented model) without changing the output mount, or by increasing the output (in output oriented model) keeping the input amount unchanged, input oriented model would be considered in this thesis work. The model below show the linear programming model (LP) of the CCR model which is also an input-oriented CCR;

$$\max \theta = \sum_{r=1}^{s} u_r\, y_{ro} \tag{3.5}$$

$$s.t \ \sum_{i=1}^{m} v_i x_{io} = 1 \tag{3.6}$$

$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \qquad j = 12,3 \ldots n$ (3.7)

$v_i \geq 0 \quad i = 1,2,3 \ldots m$ (3.8)

$u_r \geq 0 \quad r = 1,2,3 \ldots s$ (3.9)

The following model (3.10) represents the vector form of the model (3.5) above CCR linear programing model. $u$ And $v$ variables are the row vectors as output and input multipliers respectively. Which are variables in the model 3.10 and made the model be in its multiplier form,

max $uy_o$ (3.10)

$s.t.\ vx_o = 1$ (3.11)

$uY - vX \leq 0$ (3.12)

$u \geq 0$ (3.13)

$v \geq 0$ (3.14)

Where;

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} = (m\ by\ n)\ matrix, \qquad (3.15)$$

$$Y = \begin{bmatrix} y_{11} & \cdots & y_{1n} \\ \vdots & \ddots & \vdots \\ y_{s1} & \cdots & y_{sn} \end{bmatrix} = (s\ by\ n)\ matrix \qquad (3.16)$$

The model 3.17 below (envelopment form) represents the dual linear program (DLP) of the above LP model in 3.10 above,

$Min\ \theta$ (3.17)

$s.t\ \theta x_o - X\lambda \geq 0$ (3.18)

$Y\lambda - y_0 \geq 0$ (3.19)

$\lambda \geq 0$ (3.20)

$\theta$ is unrestricted (3.21)

Where; $\theta$ and λ are the real and non-negative variables respectively. And

$$\lambda = \begin{bmatrix} \lambda_1 \\ \vdots \\ \lambda_n \end{bmatrix} = \text{non negative vector}$$

Looking at model 3.10 and 3.17, a connection between the two models can be observed. The model 3.10 is called primal model and its dual model is 3.17. The primal constraint 3.11 corresponds with the real variable 3.21 in the dual program, and the constraint 3.12 in the primal corresponds with the non-negative variable in the dual problem. And can be seen that the primal variables becomes constraints in the dual model. This primal and dual relationship is summarized in table 3.1 below

Table 3.1 relationship between primal constraints and dual variables in CCR models

| Primal Constraints (in model 3.10) | Dual variables (in model 3.17) |
|---|---|
| $vx_o = 1$ | $\theta$ |
| $uY - vX \leq 0$ | $\lambda \geq 0$ |

Constraint 3.18 and 3.19 in dual model corresponds with the primal variable 3.14 and 3.13 respectively. This relationship is summarized in table 3.2 below

Table 3.2: Dual constraints and primal variables relationship

| Dual LP Constraints (in model 3.17) | Primal variable variables (in model 3.10) |
|---|---|
| $\theta x_o - X\lambda \geq 0$ | $v \geq 0$ |
| $Y\lambda \geq y_o$ | $u \geq 0$ |

## 3.3 Production Possibility Set (PPS)

Here, there has to be an assumption of at least one of every input and output vector be positive (At every DMU there has to be at least a positive integer in both the input and the output), such assumption is called semi-positive. This can be mathematically expressed as; $x_j > 0\ and\ y_j > 0$. Where, $j = 1,2, \dots n$. Pair of semi-positive Input $x \in R^m$ and Output $y \in R^s$ is called an "activity", and can be noted as $x\ and\ y$ for input and output components respectively. The region where the activity is feasible is called production Possibility set. This has the following property;

- The activities $(x_j, y_j\ )$ under observations are part of the production possibility set.
- The activities $(tx, ty)$ are part of the production possibility set, If the activities $(x\ and\ y)$ are part of the PPS and $t$ be any positive scalar. This behavior is called "Constant return to scale".
- It is feasible for any semi-positive activity $(\bar{x}\ and\ \bar{y}\ )$ be in possible possibility set (PPS) when $\bar{x} \geq x$ and $\bar{y} \leq y$, where $x$ and $y$ are activity in PPS.
- Any linear combination of semi-positive activity in possible possibility set belonged to PPS.

The production possibility set can be defined based on combination of the four PPS properties above, which defined as;

$PPS = \{(x, y)|x \geq X\lambda, \mathrm{y} \leq \mathrm{Y}\lambda, \lambda \geq 0\ \}$

Where;

- X and Y are matrices data set of $x_j\ and\ y_j$ respectively.
- λ is a semi-positive vector in $R^n$

The primal model and dual model of CCR in consideration with PPS is also represented in the model 3.10 and 3.17 respectively. But in this case the input and output variables satisfied semi-positive assumptions.

The production possibility set (PPS) of a single input (*m=1*) and output (*s*=1) is shown in the two dimensional figure below. The point *B* show the Production possibility set.

The dimensional figure below demonstrate an example showing the production possibility set (PPS) of a single input (*m=1*) and output (*s*=1). From the figure, point (C) determined the production possibility set, and the line from the origin passing through the point (C)is called Efficient frontier.

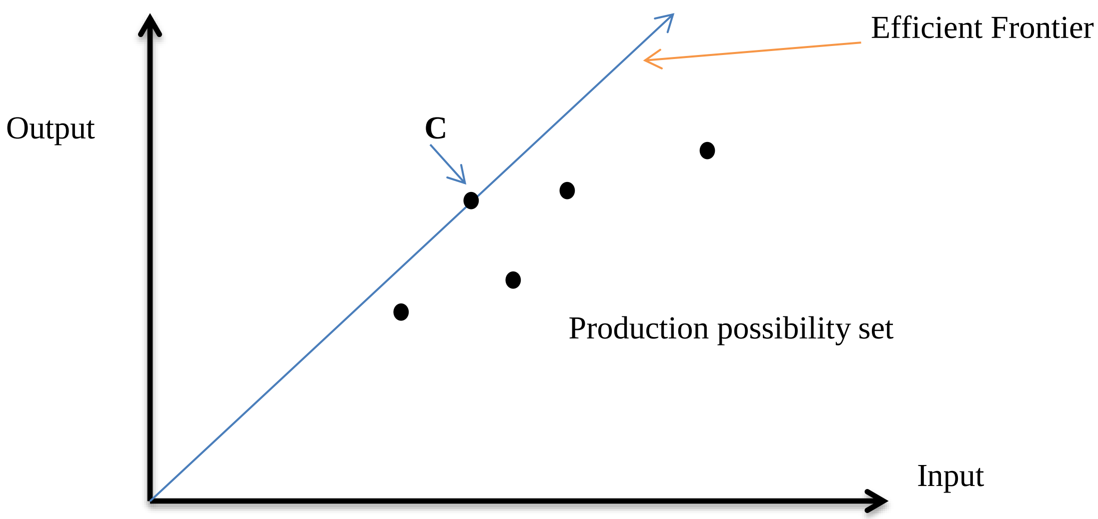


Figure 3.3: production possibility set

## 3.4 Conditions for CCR Efficiency and upgrading in-efficient DMUs efficient

The following conditions are considered for the evaluating decision making unit ($DMU_o$);

- For CCR-efficient; If $\theta^* = 1,$ And at least one of the optimal input ($v^*$) and output ($u^*$) is greater than zero ($v^* > 0\ and\ u^* > 0$), otherwise, the $DMU_o$ is inefficient.
- CCR weak efficient; if $\theta^* = 1$ and $U^*, V^* \geq 0$ and at least $U^* = 0\ or\ V^* = 0$
- For CCR in-efficient; if either $\theta^* \leq 1$ at least one of the optimal input or output is equal to zero ($v^* = 0\ \ or\ \ u^* = 0$)

In-efficient decision making units can be upgraded to efficient DMUs in DEA by either reducing the input amount or increasing the output amount. Figure 3.3 below demonstrate how to upgrade the in-efficient DMUs, where point A and B are considered in-efficient and any point on the efficient frontier is considered efficient. So, the horizontal arrow from point A shows how A moved to efficient frontier where it's considered efficient by reducing the input amount, and it's vertical arrow shows how output amount increased to reach its efficient value. Same procedure applied in upgrading point B.

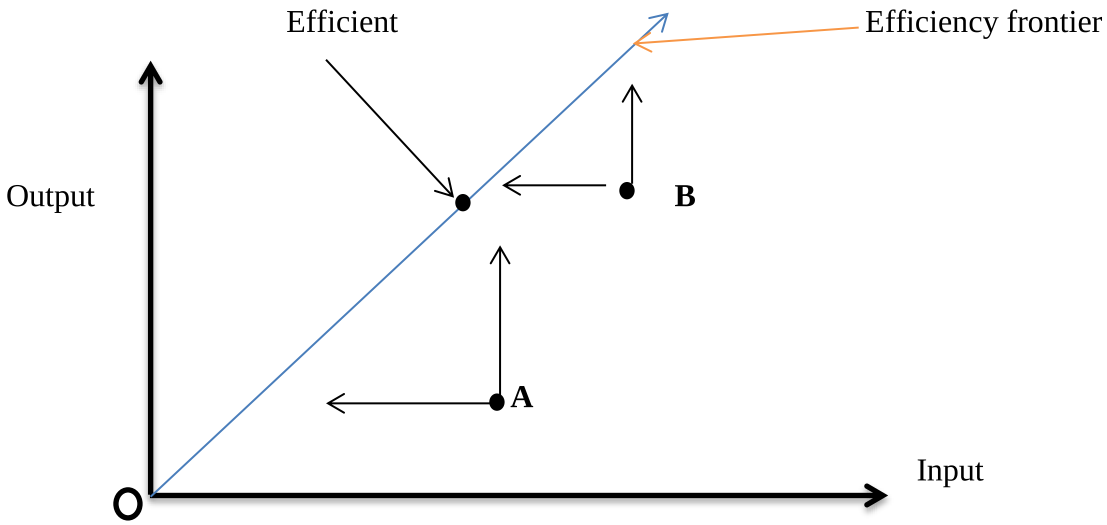


Figure 3.4: upgrading in-efficient DMUs

## 3.5 Inputs/outputs used and DMU definitions

The decision making units used in this thesis are considered as monthly, where the data received from January 2017 to December 2017 corresponds to the data received at DMU1 to DMU12, January 2018 to December 2018 corresponds to DMU13 to DMU 24, and in 2019 the data from January to August were used which corresponds to the decision making unit from DMU25 to DMU32. The correspondence of each decision making unit was clearly shown in chapter 4 table 4.1 of this thesis. Thirty two DMUs were chosen because the researcher believed that such duration would be enough to analyze the behavior of the industries' waste disposal and energy consumption that the future production process can be compared with in order to minimize its energy consumption and waste disposal for environmental safety and increasing the company's efficiency.

In this research work, three inputs and three outputs were used from a multi-product service producing company. Such as; the amount of electricity consumed, Water consumption and raw materials (chemicals) used as input, and Nylons, Cartons and washed chemicals were used as output. And keeping the production amount constant (without using the production amount as part of the output, keeping it unchanged).

**Electricity:** Electric energy is the only source of energy used in the plant, all the equipment used in processing and controlling the products, sources their energy from electricity to perform

**Water:** the plant uses two different kind of water as input in processing the products such as; deionized and distilled water. The deionized water is the input uses in processing products (like as; Shampoo gel, Softeners and body mist) and also prevents corrosion from some machines that uses hot water. The distilled water uses as the major water input, which is the water that uses in producing most of the products (like; dish detergent, hand wash, shower gel and so on) and also for other functions in the plant.

**Raw materials:** There are so many chemicals used as input-raw-materials due to the multiple products production in the plant. Some of the chemicals are; Linear alkyle benzene, ethanol, citric acid, caustic soda perfumes, Normal salt, preservatives, Ethylenediaminetetraacetic acid, dehyton (amphoteric surfactant) and glyserine. The remains of such raw materials that were directly or indirectly washed to the environment was considered as one of the output (chemical waste).

Nylons waste and cartons waste are part of the output considered because the disposal of such waste to environment may cause lots of diseases to human life such as damaging the human reproductive system and also human immune system, which were discussed in the second chapter of this thesis.

# Chapter 4

# DATA COLLECTION

As discussed in the last chapter, three inputs and outputs were used in this research. The inputs variables are; water consumption, electricity consumption and chemical raw materials used. While the outputs are; Nylon waste, carton waste and chemical waste. And the referenced industry is; Dagli Cosmetics and Cleaners Production Company located at Number 5 Kule Sokak, Harika Mahallesi, Asaggi Maras, Cyprus.

## 4.1 Input

In this part, the application and means of delivery to the factory of the three input variables is mentioned is mentioned. The techniques that the researcher used in quantifying such variables were also explained in this section.

### 4.1.1 Electricity

Electricity is the major source of energy used in the factory. The machines used in converting the basic raw materials to the final products consume electric energy for their functions. It’s also the energy used for the machines in testing and controlling the finished products. The devices used in temperature regulation of the factory for workers comfort sources its energy also from electric energy.

The whole factory’s electric consumption distributed from one unit, and it first passes through an electric consumption record meter. The meter has inserted SIM card that records the daily electric consumption of the plant and then automatically sends it to one of the electric distribution and regulatory company of northern Cyprus called “KIB-TEK”. The KIB-TEK accumulates the daily recorded electric consumption monthly. They send the electric bill together with the amount of electricity (in kilowatts) consumed in that month. So, the company keeps record for their monthly electric consumption. Thirty two months of electric consumption (from January 2017 to August 2019) was received from the company and used.

#### 4.1.2 Water Consumption

Raw water from underground is pumped to the factory’s water treatment plant. Two forms of purified water are processed in the treatment plant. The first one is distilled water, which is the major form of water used in the factory, and the second one is deionized water. Both the two form of water are channeled to their individual storage tanks for production and other purposes. During every production, the quantity needed to feed any mixer or reactor is recoded in a book that is always kept close to each of the water flow meters. The water flow meter shows the total water consumed in the whole productions using that meter.  The researcher sums the whole quantity of water recorded when feeding each mixer/reactor in each of the flow meter unit in monthly bases for thirty two months from January 2017 to August 2019.

#### 4.1.3 Chemical raw materials

In each production, there is amount of different chemicals used in processing individual products. The factory keeps records of the receipts used in each production. The receipts contains the amount of each raw materials used. The researcher manually sums the whole raw materials amount from the whole products production receipts for every month for thirty two months, from January 2017 to August 2019.

## 4.2 Output

The methods used in quantifying and receiving the output variables are explained here. An equation (4.1 and 4.2) was developed by the researcher for quantifying the waste chemicals in the factory, which was shown and explained in this section.

### 4.2.1 Nylon waste

There are three form of nylon used in the factory and each develop some waste to the environment. The first type receives as a wrapper for plastic bottles from plastic company to the factory. The second type is the nylon receives by packaging some powdered chemicals from chemical market to the factory. And the last nylon type receives from rolled nylon used in processing sachets in the factory. The first two form of nylons mentioned, disposes out as waste, and the company's management is taking monthly record of the disposal. And the last form of the nylon waste quantifies from the total poorly processed sachets used in some powdered detergents packaging in the factory. So due to the small weight of nylon, all the forms of nylons are monthly quantified by the factory management due to unanticipated demands from environmental hazard regulatory bodies. Like ISO that visits the factory once in every year. Thirty two months records of all the nylon waste was used in this research (from January 2017 to August 2019).

### 4.2.2 Carton waste

The sources of cartons in the factory are in the form of carton boxes. Cartons arrive at the factory as containers for hand gloves (hand protector), others as containers for powdered chemicals. But a larger number of carton boxes are for packaging the finished products, the cartons are occasionally wasted in the process due to mishandling or used not for its intended purpose and disposed off after. The hand gloves and the powdered container are always disposed out once empty. Thus, the estimated wasted (disposed) amount record was received from the factory’s manager for the duration of thirty two months (January 2017 to August 2019).

### 4.2.3 Washed chemicals

In each mixer/reactor there is a scale showing the amount of raw materials present in every production, and also the machines used in filling the products showing the total amount of the products filled. The company’s receipts contained production amount, number of bottles filled and quantity of the product that filled each bottle. So total receipts for every month were considered in computing the difference between the production amount and total amount filled the whole bottles. The difference is due to the waste that results from the products stained in the mixer/reactor, the filling machines and testing the products. All these difference later washed away as a result of cleaning process, which exposes to the environment and of course increases environmental hazard potential. The researcher developed the mathematical relation below in the factory to quantify the total monthly waste of chemical raw materials.

$b = Bottles\ capacity$

$e = Number\ of\ bottles\ filled$

$i = number\ of\ different\ capacity\ (i = 1,2, \ldots n)$

$b_i = bottles\ with\ i^{th}\ \ capacity$

$e_i = number\ of\ bottles\ filled\ for\ each\ i^{th} Capacity$

$l = Expected\ prduction\ amount$

$O = amount\ of\ chemical\ wasted\ per\ production$

$$O = l - \sum_{i=1}^{n} b_i\, e_i \tag{4.1}$$

$G = monthly\ total\ waste$

$r = number\ of\ monthly\ productions$

$O_r = monthly\ amount\ of\ waste\ per\ monthly\ production$

$$G = \sum_{r=1}^{m} O_r \tag{4.2}$$

## 4.3 Variables Correlation

The Correlation between the Inputs and Outputs Variables used in this research were shown in Table 4.0 below. It can be seen from the result that, there is a strong relationship between Electricity Consumption and Water consumption, Electricity Consumption and Chemical Waste Water Consumption and Chemical raw material, Water Consumption and Chemical raw material, Water Consumption and Nylon Waste, Chemical raw material and Chemical Waste, Nylon Waste and Chemical Waste, Nylon Waste and Carton Waste. While in the cases of variables that are weakly correlated, between Electricity with Chemical Consumption, Nylon Waste and Carton Waste are weakly correlated. Between Water Consumption with Carton Waste were also weakly correlated. Generally, it can be seen that there is no any set of variables that were not correlated, the negative value shows the invers proportionality of the variables, while the others are directly proportional.

Table 4.1: Variables Correlation

| **Variables** | electricity | water | Chemicals | Nylon waste | Carton waste | Chemical waste |
|---|---|---|---|---|---|---|
| electricity | 1 | | | | | |
| water | 0.661276 | 1 | | | | |
| Chemicals | 0.366913 | 0.80064 | 1 | | | |
| Nylon waste | 0.260769 | 0.487887 | 0.246812 | 1 | | |
| Carton waste | 0.079349 | 0.183438 | -0.02359 | 0.772678 | 1 | |
| Chemical waste | 0.494978 | 0.844808 | 0.70747 | 0.602959 | 0.321101 | 1 |

The data received from the chemical plant for the purpose of this research are represented in table 4.1 below. Where Input1 is defined as electricity consumption, Input2 as Water consumption and Input3 as chemicals raw materials used, and the output variables, Output1 is defined as Nylon waste, Output2 as Carton and the last output as the chemicals waste.

Table 4.2: Input and Output data

| | | | Input1 | Input2 | Input3 | Output1 | Output2 | Output3 |
|---|---|---|---|---|---|---|---|---|
| Years | Months | DMU | electricity | water | Chemicals | Nylon waste | Carton waste | Chemical waste |
| 2017 | January | DMU01 | 7000 | 179825.4 | 24376.33 | 93.2 | 107.9 | 41.95926 |
| | February | DMU02 | 7400 | 120260 | 13996.36 | 109.65 | 89.7 | 31.25401 |
| | March | DMU03 | 9000 | 151536 | 16800.73 | 138.835 | 134.27 | 31.29547 |
| | April | DMU04 | 6600 | 151317.2 | 18874.32 | 127.085 | 154.995 | 35.49018 |
| | May | DMU05 | 6600 | 129439.6 | 13904.37 | 153.13 | 335.29 | 31.53568 |
| | June | DMU06 | 6800 | 107540.5 | 13577.74 | 82.435 | 83.11 | 14 |
| | July | DMU07 | 5600 | 125958.9 | 23510.25 | 86.34 | 74.22 | 29.58243 |
| | August | DMU08 | 10000 | 174222.2 | 24633.47 | 103.88 | 82 | 43.70454 |
| | September | DMU09 | 9800 | 205776.9 | 22357.13 | 111.91 | 111.16 | 47.90814 |
| | October | DMU10 | 11000 | 242940 | 27588.55 | 111.81 | 64.94 | 56.2485 |
| | November | DMU11 | 8600 | 253379.5 | 38196.46 | 132.15 | 110.86 | 52.48368 |
| | December | DMU12 | 10200 | 177764.7 | 19971.34 | 70.5 | 91.25 | 12.4 |
| 2018 | January | DMU13 | 10200 | 195019.5 | 22007.78 | 93.8 | 107.5 | 43.57977 |
| | February | DMU14 | 7000 | 152857.5 | 16117.05 | 83.4 | 55.31 | 30.53758 |
| | March | DMU15 | 8200 | 121287.5 | 14892.6 | 105.9 | 91.8 | 28.17519 |
| | April | DMU16 | 7400 | 155738.2 | 17459.44 | 166.5 | 124.1 | 36.66483 |
| | May | DMU17 | 8400 | 161474 | 15987.52 | 177.1 | 187.9 | 39.08061 |
| | June | DMU18 | 8400 | 162865 | 16685.5 | 195 | 179 | 34.45919 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | July | DMU19 | 7800 | 155412.6 | 25934.11 | 138 | 179.2 | 36.49986 |
| | August | DMU20 | 6200 | 128907.2 | 14417.25 | 106.28 | 151.14 | 28.26912 |
| | September | DMU21 | 10200 | 236500.5 | 24223.07 | 218.5 | 309.1 | 57.30188 |
| | October | DMU22 | 10400 | 245780.4 | 24551.35 | 260.28 | 288.4 | 58.70976 |
| | November | DMU23 | 10200 | 197748.6 | 22118.06 | 173.1 | 216 | 41.60823 |
| | December | DMU24 | 8400 | 158537.4 | 18569.03 | 157.9 | 247.5 | 40.29129 |
| 2019 | January | DMU25 | 8324.2 | 86343.55 | 10454.15 | 61.2 | 134.8 | 20.32752 |
| | February | DMU26 | 7022.22 | 127349.8 | 15617.03 | 72 | 108 | 29.81433 |
| | March | DMU27 | 5857.3 | 155157 | 13462.65 | 114.6 | 145.7 | 30.29096 |
| | April | DMU28 | 5875.3 | 150680.4 | 21920.29 | 158.85 | 205.35 | 34.52014 |
| | May | DMU29 | 6478.87 | 132774.8 | 15524.89 | 119.7 | 149.15 | 31.04978 |
| | June | DMU30 | 6869.68 | 123278.3 | 14575.44 | 136.28 | 189.65 | 29.9682 |
| | July | DMU31 | 6489.54 | 186297.2 | 28974.79 | 154.5 | 145.3 | 45.71579 |
| | August | DMU32 | 7000 | 149751 | 17009.58 | 95.7 | 101.4 | 29.34987 |

The computed Inverse of Nylon waste, carton waste and chemicals waste that used as output are shown in table 4.2 below.

Table 4.3: Inverse of Output

| DMU | Nylon waste | Carton waste | Chemicals waste | DMU | Nylon waste | Carton waste | Chemicals waste |
|---|---|---|---|---|---|---|---|
| DMU1 | 0.01073 | 0.00927 | 0.02383 | DMU17 | 0.00565 | 0.00532 | 0.02559 |
| DMU2 | 0.00912 | 0.01115 | 0.032 | DMU18 | 0.00513 | 0.00559 | 0.02902 |
| DMU3 | 0.0072 | 0.00745 | 0.03195 | DMU19 | 0.00725 | 0.00558 | 0.0274 |
| DMU4 | 0.00787 | 0.00645 | 0.02818 | DMU20 | 0.00941 | 0.00662 | 0.03537 |
| DMU5 | 0.00653 | 0.00298 | 0.03171 | DMU21 | 0.00458 | 0.00324 | 0.01745 |
| DMU6 | 0.01213 | 0.01203 | 0.07143 | DMU22 | 0.00384 | 0.00347 | 0.01703 |
| DMU7 | 0.01158 | 0.01347 | 0.0338 | DMU23 | 0.00578 | 0.00463 | 0.02403 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DMU8 | 0.00963 | 0.0122 | 0.02288 | DMU24 | 0.00633 | 0.00404 | 0.02482 |
| DMU9 | 0.00894 | 0.009 | 0.02087 | DMU25 | 0.01634 | 0.00742 | 0.04919 |
| DMU10 | 0.00894 | 0.0154 | 0.01778 | DMU26 | 0.01389 | 0.00926 | 0.03354 |
| DMU11 | 0.00757 | 0.00902 | 0.01905 | DMU27 | 0.00873 | 0.00686 | 0.03301 |
| DMU12 | 0.01418 | 0.01096 | 0.08065 | DMU28 | 0.0063 | 0.00487 | 0.02897 |
| DMU13 | 0.01066 | 0.0093 | 0.02295 | DMU29 | 0.00835 | 0.00671 | 0.03221 |
| DMU14 | 0.01199 | 0.01808 | 0.03275 | DMU30 | 0.00734 | 0.00527 | 0.03337 |
| DMU15 | 0.00944 | 0.01089 | 0.03549 | DMU31 | 0.00647 | 0.00688 | 0.02187 |
| DMU16 | 0.00601 | 0.00806 | 0.02727 | DMU32 | 0.01045 | 0.00986 | 0.03407 |

The Normalized input and output data is shown in table 4.3 below. This was computed from table 4.1and table 4.2 above. The normalized data for the input and output (Input1, Input2, Input3, and Output1, Output2 and Output3) was calculated by dividing each input number under for example input1with the highest number in that input1, same procedure also applied for input2 and input3, and also output1, output2 and output3. But table 4.1 was considered for computing the input normalization and table 4.2 was considered for computing the output normalized data.

Table 4.4: Normalized Input and Output Data

| DMU | input1 | input2 | input3 | output1 | output2 | output3 |
|---|---|---|---|---|---|---|
| DMU01 | 0.636364 | 0.709708 | 0.638183 | 0.656647 | 0.512602 | 0.295525 |
| DMU02 | 0.672727 | 0.474624 | 0.366431 | 0.558135 | 0.616608 | 0.39675 |
| DMU03 | 0.818182 | 0.598059 | 0.43985 | 0.440808 | 0.411929 | 0.396224 |
| DMU04 | 0.6 | 0.597196 | 0.494138 | 0.481564 | 0.356849 | 0.349393 |
| DMU05 | 0.6 | 0.510853 | 0.364022 | 0.399657 | 0.164961 | 0.393206 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DMU06 | 0.618182 | 0.424425 | 0.355471 | 0.742397 | 0.6655 | 0.885716 |
| DMU07 | 0.509091 | 0.497115 | 0.615509 | 0.70882 | 0.745213 | 0.419169 |
| DMU08 | 0.909091 | 0.687594 | 0.644915 | 0.589137 | 0.674509 | 0.283724 |
| DMU09 | 0.890909 | 0.812129 | 0.585319 | 0.546864 | 0.497569 | 0.258829 |
| DMU10 | 1 | 0.958799 | 0.72228 | 0.547353 | 0.851705 | 0.220451 |
| DMU11 | 0.781818 | 1 | 1 | 0.463106 | 0.498915 | 0.236264 |
| DMU12 | 0.927273 | 0.701575 | 0.522858 | 0.868078 | 0.606134 | 1.000002 |
| DMU13 | 0.927273 | 0.769673 | 0.576173 | 0.652447 | 0.514509 | 0.284536 |
| DMU14 | 0.636364 | 0.603275 | 0.421952 | 0.733807 | 0.999995 | 0.406058 |
| DMU15 | 0.745455 | 0.478679 | 0.389895 | 0.577899 | 0.602503 | 0.440104 |
| DMU16 | 0.672727 | 0.614644 | 0.457096 | 0.367565 | 0.445687 | 0.338199 |
| DMU17 | 0.763636 | 0.637281 | 0.41856 | 0.345565 | 0.294357 | 0.317294 |
| DMU18 | 0.763636 | 0.642771 | 0.436834 | 0.313844 | 0.308993 | 0.359847 |
| DMU19 | 0.709091 | 0.613359 | 0.678966 | 0.443475 | 0.308648 | 0.339728 |
| DMU20 | 0.563636 | 0.508751 | 0.37745 | 0.575833 | 0.36595 | 0.438642 |
| DMU21 | 0.927273 | 0.933384 | 0.634171 | 0.280089 | 0.178938 | 0.216398 |
| DMU22 | 0.945455 | 0.970009 | 0.642765 | 0.23513 | 0.191781 | 0.211209 |
| DMU23 | 0.927273 | 0.780444 | 0.57906 | 0.35355 | 0.256064 | 0.298019 |
| DMU24 | 0.763636 | 0.625692 | 0.486145 | 0.387584 | 0.223474 | 0.307759 |
| DMU25 | 0.756745 | 0.340768 | 0.273694 | 0.999992 | 0.41031 | 0.610012 |
| DMU26 | 0.638384 | 0.502605 | 0.408861 | 0.849993 | 0.512127 | 0.415908 |
| DMU27 | 0.532482 | 0.61235 | 0.352458 | 0.534027 | 0.379614 | 0.409364 |
| DMU28 | 0.534118 | 0.594683 | 0.573883 | 0.385266 | 0.269344 | 0.359211 |
| DMU29 | 0.588988 | 0.524015 | 0.406448 | 0.511274 | 0.370833 | 0.39936 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DMU30 | 0.624516 | 0.486536 | 0.381591 | 0.449072 | 0.291641 | 0.413773 |
| DMU31 | 0.589958 | 0.73525 | 0.758573 | 0.396113 | 0.380659 | 0.271242 |
| DMU32 | 0.636364 | 0.591015 | 0.445318 | 0.639493 | 0.545461 | 0.42249 |

# Chapter 5

# RESULTS AND DISCUSSION

In this chapter the researcher present and discusses the following results CCR efficiency result, benchmark (Lamdas) of CCR result, Weight of CCR result, result for input target of CCR and the result for output target of CCR. The above results were received from the analysis of input and output data of each decision making (DMU) of the data from table 4.3 using PIM-DEA software.

## 5.1 CCR Efficiency

The efficiency of every decision making unit is shown in table 5.1. This is the efficiency result obtained by solving the CCR model 3.10 (multiplier form) using PIM-DEA software. Each decision making unit has its own corresponding efficiency obtained using their desired input and output from table 4.3 (Normalized input and output).

Table 5.1: CCR Efficiency Result

| **DMUs** | **Efficiency** | **DMUs** | **Efficiency** | **DMUs** | **Efficiency** | **DMUs** | **Efficiency** |
|---|---|---|---|---|---|---|---|
| DMU01 | 75.04 | DMU09 | 48.47 | DMU17 | 36.96 | DMU25 | 100 |
| DMU02 | 80.39 | DMU10 | 54.2 | DMU18 | 36.36 | DMU26 | 99.01 |
| DMU03 | 46.74 | DMU11 | 43.28 | DMU19 | 47.12 | DMU27 | 76.86 |
| DMU04 | 60.47 | DMU12 | 77.44 | DMU20 | 78.19 | DMU28 | 56.49 |
| DMU05 | 53.33 | DMU13 | 54.54 | DMU21 | 23.15 | DMU29 | 66.6 |
| DMU06 | 100 | DMU14 | 100 | DMU22 | 19.52 | DMU30 | 56.9 |
| DMU07 | 100 | DMU15 | 78.49 | DMU23 | 29.71 | DMU31 | 49.42 |
| DMU08 | 60.42 | DMU16 | 49.53 | DMU24 | 39.16 | DMU32 | 77.88 |

Table 5.1 above, shows the efficiency results obtained for every decision making unit. It can be seen that; DMU6 (June, 2017), DMU7 (July, 2017), DMU14 (February, 2018) and DMU25 (January, 2019) have the optimum (highest) efficiency result and are also considered on the efficient frontier hyper plan alternatively. In this research, the inverse of different wastes amount were used as outputs. As such, the higher the output value the lower the amount of waste, and the lower output value the higher the amount of waste. Therefore, it can now be discussed that, the above DMUs having the optimum efficiency have the lowest waste disposal among the whole thirty two decision making units considered, followed by DMU26 (February, 2019) which was very closed to optimal efficiency. The lowest efficiency found to be in DMU22 (October, 2018) with 19.52% efficiency, which means it’s decision making unit has the highest waste disposal among the considered DMUs, followed by DMU21 (September, 2018) in the waste disposal amount. It can be seen that the

duration with the densely waste disposal was between DMU17 to DMU18 (May to June, 2018), and also between DMU21 to DMU24 (September to December, 2018).

The tolerance range of the DMUs waste disposal may be considered between 80% to 100% efficiency. And a focus can be made in order to increase the efficiency of DMUs that has at least the 80% efficiency, Such DMUs are close to optimum efficiency. Thus, little effort is needed to minimize their waste disposal amount, which will lead to the higher amount of output or by minimizing the energy amount. Percentage of this tolerance range can be computed to know the percentage of the months that can be considered in all the DMUs so as to know the kind of effort and strategy needed to make sure that this waste disposal can be minimal to the environment. The DMUs having efficiency between efficiency 80% to 100% are; DMU2, DMU6, DMU7, DMU14, DMU25 and DMU26, which is 6 units out of 32.

Percentage of tolerance Months (DMUs) $= \frac{6}{32} \times 100 = 19\%$.

The discussion of result found in table 5.1 is summarized in figure 5.1 below

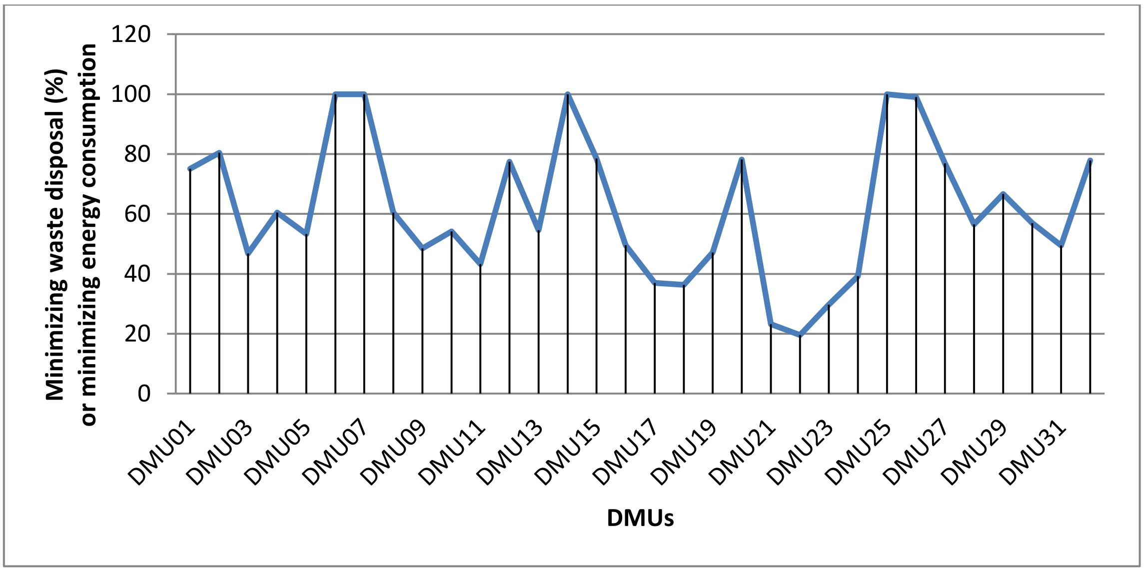


Figure 5.1: Extent of minimizing waste disposal in each DMU

## 5.2 Lamdas of CCR

The benchmark result obtained by solving model 3.17 (envelopment form) using PIM- DEA software is shown here in figure 5.2. It shows a benchmark to compare in upgrading inefficient DMUs efficient.

Table 5.2a: Benchmark result

| Name | DMU06 | DMU07 | DMU14 | DMU25 | Name | DMU06 | DMU07 | DMU14 | DMU25 |
|---|---|---|---|---|---|---|---|---|---|
| DMU01 | 0 | 0.71 | 0 | 0.15 | DMU17 | 0.25 | 0.01 | 0.08 | 0.09 |
| DMU02 | 0.42 | 0 | 0.34 | 0 | DMU18 | 0.38 | 0 | 0.06 | 0 |
| DMU03 | 0.31 | 0 | 0.17 | 0.09 | DMU19 | 0.17 | 0.41 | 0 | 0.03 |
| DMU04 | 0.14 | 0.35 | 0 | 0.13 | DMU20 | 0.21 | 0.25 | 0 | 0.24 |
| DMU05 | 0.35 | 0.08 | 0 | 0.09 | DMU21 | 0.11 | 0.13 | 0 | 0.11 |
| DMU06 | 1 | 0 | 0 | 0 | DMU22 | 0.16 | 0.09 | 0 | 0.05 |
| DMU07 | 0 | 1 | 0 | 0 | DMU23 | 0.19 | 0.11 | 0 | 0.13 |
| DMU08 | 0.37 | 0 | 0.43 | 0 | DMU24 | 0.17 | 0.14 | 0 | 0.16 |
| DMU09 | 0 | 0.17 | 0.28 | 0.22 | DMU25 | 0 | 0 | 0 | 1 |
| DMU10 | 0 | 0 | 0.85 | 0 | DMU26 | 0 | 0.41 | 0 | 0.56 |
| DMU11 | 0 | 0.6 | 0.05 | 0 | DMU27 | 0.2 | 0.22 | 0 | 0.23 |
| DMU12 | 1.09 | 0 | 0 | 0.06 | DMU28 | 0.29 | 0.24 | 0 | 0 |
| DMU13 | 0 | 0.21 | 0.22 | 0.35 | DMU29 | 0.21 | 0.23 | 0 | 0.19 |
| DMU14 | 0 | 0 | 1 | 0 | DMU30 | 0.33 | 0.11 | 0 | 0.13 |
| DMU15 | 0.53 | 0 | 0.25 | 0 | DMU31 | 0.08 | 0.47 | 0 | 0 |
| DMU16 | 0.24 | 0.07 | 0.23 | 0 | DMU32 | 0.1 | 0.28 | 0.17 | 0.24 |

Based on the result obtained in table 5.1, it shows that DMU6, DMU7, DMU14 and DMU25 has the optimum efficiency, which made them a benchmark for comparing all the decision making units when making inefficient DMUs efficient, this benchmark is shown in table 5.2. It can be seen that DMU1 can be compared with

DMU7 and DMU25, but it can best be compared with DMU7. This means that, DMU7 is the best decision making unit among the optimal DMUs that the DMU1 can be compared with in minimizing waste disposal or minimizing energy consumption in DMU1. DMU2 can be compared with DMU6 and DMU14, but it can best be compared with DMU6 and cannot be even compared with DMU7 and DMU25. Generally, the inefficient DMUs can be compared with the positive and nonzero values of lamdas (bencmark) of the optimal DMUs, and the greatest lamda value is the best benchmark. Comparing the rest of the DMUs can best be describes in table 5.2.1 below. This shows the best benchmark of each DMU. The table can also help to find the number of times that each of the optimal DMUs is used as a benchmark for the inefficient DMUs. It can be seen that DMU6 can be used as a benchmark for upgrading the efficiency of 14 decision making units, DMU7 for 10 decision making units, DMU14 for 4 decision making unit and DMU25 for 4 decision making unit. So, DMU6 is the most referenced benchmark, followed by DMU7, and lastly DMU14 and DMU25 among the best benchmarks. The number of referenced DMUs for each bench mark is shown in Figure 5.2 below.

Table 5.2b: Best benchmark per DMU

| DMUs | Best Benchmark | DMUs | Best Benchmark | DMUs | Best Benchmark |
|---|---|---|---|---|---|
| DMU1 | DMU7 | DMU12 | DMU6 | DMU23 | DMU6 |
| DMU2 | DMU6 | DMU13 | DMU25 | DMU24 | DMU6 |
| DMU3 | DMU6 | DMU14 | DMU14 | DMU25 | DMU25 |
| DMU4 | DMU7 | DMU15 | DMU6 | DMU26 | DMU25 |
| DMU5 | DMU6 | DMU16 | DMU6 | DMU27 | DMU25 |
| DMU6 | DMU6 | DMU17 | DMU6 | DMU28 | DMU6 |
| DMU7 | DMU7 | DMU18 | DMU6 | DMU29 | DMU7 |
| DMU8 | DMU14 | DMU19 | DMU7 | DMU30 | DMU6 |
| DMU9 | DMU14 | DMU20 | DMU7 | DMU31 | DMU7 |
| DMU10 | DMU14 | DMU21 | DMU7 | DMU32 | DMU7 |
| DMU11 | DMU7 | DMU22 | DMU6 | | |

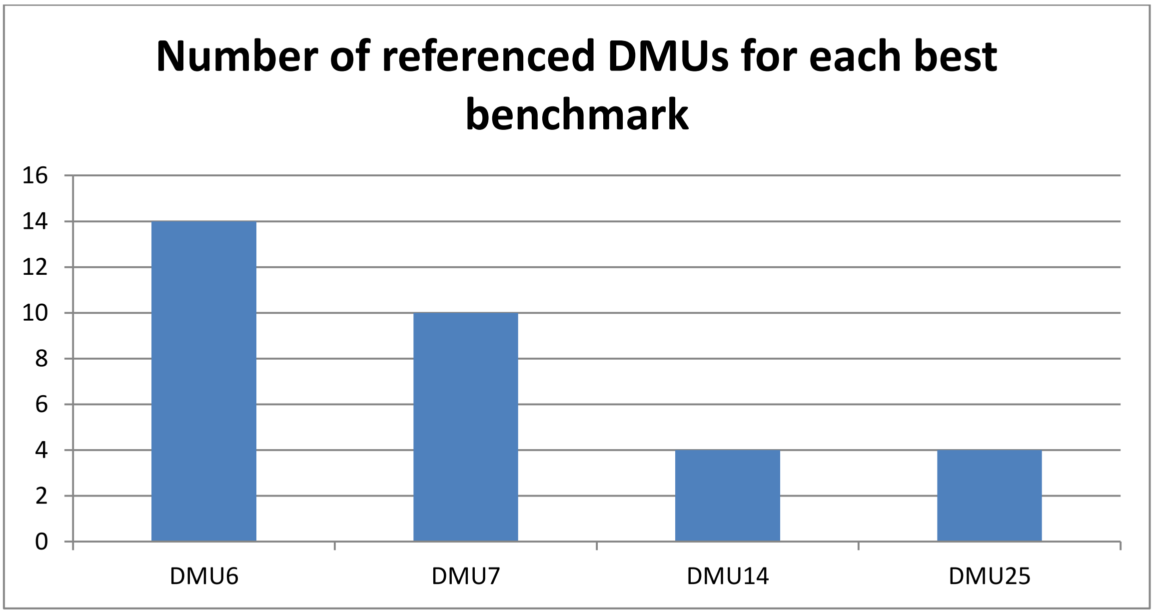


Figure 5.2: Number of DMUs that were referenced for each of the best benchmark

## 5.3 Weights of CCR

The contribution and also the importance of each of the input and output used in the efficiency evaluation of each of the decision making unit used is shown in table 5.3 below.

Table 5.3: Weights of CCR Result

| Name | input1 | input2 | input3 | output1 | output2 | output3 |
|---|---|---|---|---|---|---|
| DMU01 | 1.48 | 0 | 0.1 | 1.14 | 0 | 0 |
| DMU02 | 0 | 2.11 | 0 | 0.19 | 1.13 | 0 |
| DMU03 | 0 | 0 | 2.27 | 0.21 | 0.73 | 0.19 |
| DMU04 | 1.59 | 0 | 0.1 | 1.08 | 0 | 0.24 |
| DMU05 | 1.61 | 0 | 0.1 | 1.09 | 0 | 0.24 |
| DMU06 | 1.56 | 0 | 0.09 | 1.06 | 0 | 0.24 |
| DMU07 | 1.46 | 0 | 0.42 | 1.09 | 0.3 | 0 |
| DMU08 | 0 | 1.45 | 0 | 0.13 | 0.78 | 0 |
| DMU09 | 0.94 | 0 | 0.27 | 0.71 | 0.2 | 0 |
| DMU10 | 1 | 0 | 0 | 0 | 0.64 | 0 |
| DMU11 | 1.28 | 0 | 0 | 0.28 | 0.61 | 0 |
| DMU12 | 1.04 | 0 | 0.06 | 0.71 | 0 | 0.16 |
| DMU13 | 0.91 | 0 | 0.26 | 0.69 | 0.19 | 0 |
| DMU14 | 1.56 | 0 | 0.01 | 0 | 0.8 | 0.5 |
| DMU15 | 0 | 2.09 | 0 | 0.19 | 1.12 | 0 |
| DMU16 | 1.48 | 0 | 0.01 | 0 | 0.76 | 0.47 |
| DMU17 | 1.13 | 0 | 0.33 | 0.81 | 0.24 | 0.06 |
| DMU18 | 0 | 0 | 2.29 | 0 | 0.85 | 0.28 |
| DMU19 | 1.33 | 0 | 0.08 | 0.91 | 0 | 0.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DMU20 | 1.71 | 0 | 0.1 | 1.16 | 0 | 0.26 |
| DMU21 | 1.04 | 0 | 0.06 | 0.71 | 0 | 0.16 |
| DMU22 | 1.02 | 0 | 0.06 | 0.69 | 0 | 0.15 |
| DMU23 | 1.04 | 0 | 0.06 | 0.71 | 0 | 0.16 |
| DMU24 | 1.26 | 0 | 0.08 | 0.86 | 0 | 0.19 |
| DMU25 | 1.29 | 0 | 0.08 | 0.88 | 0 | 0.2 |
| DMU26 | 1.5 | 0 | 0.1 | 1.16 | 0 | 0 |
| DMU27 | 1.81 | 0 | 0.11 | 1.23 | 0 | 0.27 |
| DMU28 | 1.87 | 0 | 0 | 1.13 | 0 | 0.36 |
| DMU29 | 1.63 | 0 | 0.1 | 1.11 | 0 | 0.25 |
| DMU30 | 1.54 | 0 | 0.09 | 1.05 | 0 | 0.23 |
| DMU31 | 1.7 | 0 | 0 | 1.03 | 0 | 0.32 |
| DMU32 | 1.31 | 0 | 0.38 | 0.93 | 0.28 | 0.07 |

Based on the contribution of each of the input and output for the efficiency of each of the individual decision making unit shown above, It can be seen that only input1, Input3 and output1 contributed in the efficiency evaluation of DMU1, which means that electricity consumption (input1) and Chemical raw materials (input3), and Nylon waste (Output1) were the only variables that contributed in the efficiency evaluation of January 2017 (DMU1), the values of the remaining variables such as Water consumption (input2), Carton waste (output2) and washed chemicals (output3) didn't affect the efficiency evaluation in that decision making unit (DMU1) that is why they had zero weight value in DMU1. But in the case of DMU2 (February, 2017), water consumption (Input2) becomes the only important input variable in the efficiency evaluation of that decision making unit with output1 (Nylon waste) and output 2

(Carton waste) as the output variables. In DMU3, all of the output variables were contributed and only input3 as the input variable that contributed. Interestingly, DMU10 shows how decision making unit with 3 inputs and 3 outputs becomes one input and one output, because the weights for the two remaining inputs and outputs were not significant. Generally, any variable with zero weight in a decision making unit, means that variable didn't contribute in the efficiency evaluation of that DMU. So with this knowledge of generalization, the variables that are important in the efficiency evaluation of each of the remaining DMUs (in table 5.3) can be identified based on their nonzero value of weight.

In the efficiency evaluation of each of the thirty two DMUs shown in the table above can be seen that Input1 (Electricity consumption) and Output 1 (Nylon Waste) are the most important variable used in the efficiency evaluation of whole the DMUs, followed by Output 2 (Carton Waste), Input 3 (Chemical Raw materials), Input 2 (Water Consumption) and finally output3 (Chemical Waste). Which are shown in figure 5.3 below.

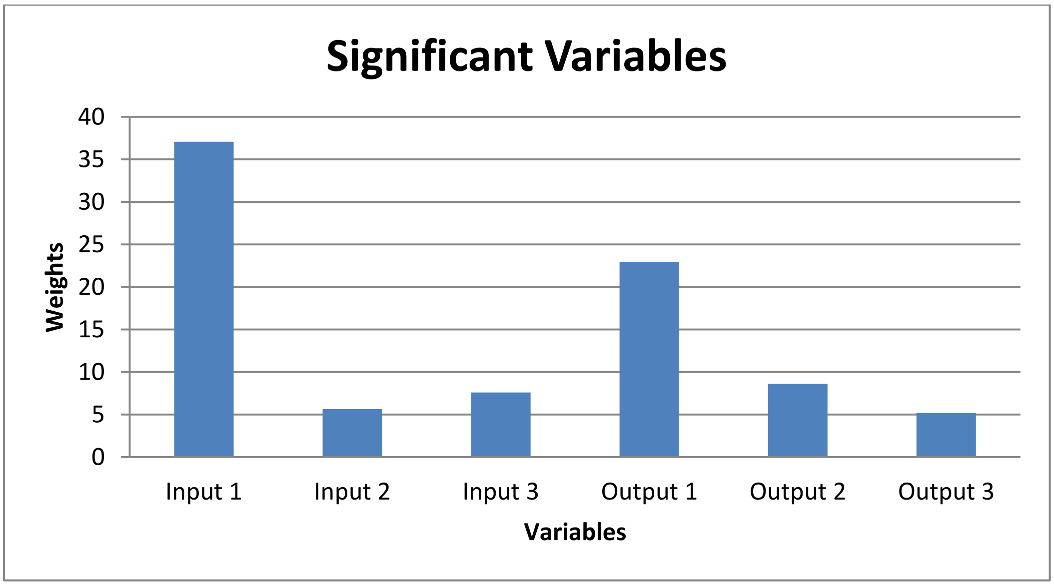


Figure 5.3: Significant Variables

Figure 5.4 below shows the weight and importance of each input/output variables used at DMU10

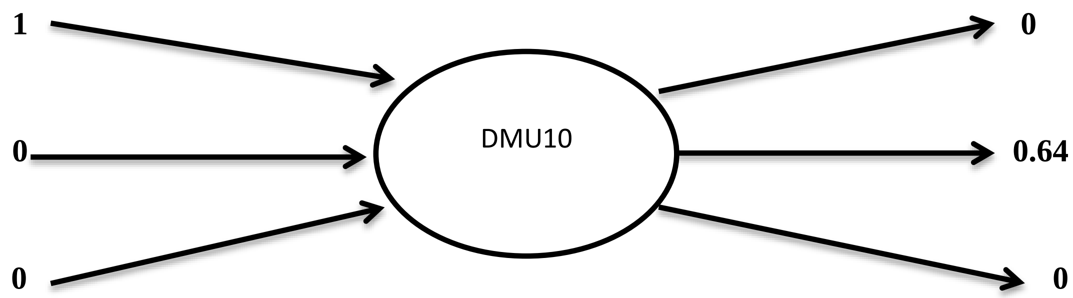


Figure 5.4: weights of DMU10

## 5.4 Target of CCR

As discussed before in the methodology part of this thesis (Chapter 3), Efficiency of a DMU can be upgraded either by reducing the input amount (input weight) or by increasing the output weight, which are shown in table 5.4 and table 5.5.The target for each of the input and output variables to be reached in order to increase the efficiency of each DMU, and the their percentage gain are shown in the two tables.

Table 5.4: Target of CCR for Input

| Name | input1 Value | input1 Target | input1 Gain(%) | input2 Value | input2 Target | input2 Gain(%) | input3 Value | input3 Target | input3 Gain(%) |
|---|---|---|---|---|---|---|---|---|---|
| DMU01 | 0.64 | 0.48 | -24.96 | 0.71 | 0.41 | -42.91 | 0.64 | 0.48 | -24.96 |
| DMU02 | 0.67 | 0.47 | -29.64 | 0.47 | 0.38 | -19.61 | 0.37 | 0.29 | -20.52 |
| DMU03 | 0.82 | 0.36 | -55.4 | 0.6 | 0.26 | -55.93 | 0.44 | 0.21 | -53.26 |
| DMU04 | 0.6 | 0.36 | -39.53 | 0.6 | 0.28 | -53.72 | 0.49 | 0.3 | -39.53 |
| DMU05 | 0.6 | 0.32 | -46.67 | 0.51 | 0.22 | -57.9 | 0.36 | 0.19 | -46.67 |
| DMU06 | 0.62 | 0.62 | 0 | 0.42 | 0.42 | 0 | 0.36 | 0.36 | 0 |
| DMU07 | 0.51 | 0.51 | 0 | 0.5 | 0.5 | 0 | 0.62 | 0.62 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DMU08 | 0.91 | 0.5 | -44.85 | 0.69 | 0.42 | -39.58 | 0.64 | 0.31 | -51.58 |
| DMU09 | 0.89 | 0.43 | -51.53 | 0.81 | 0.33 | -59.51 | 0.59 | 0.28 | -51.53 |
| DMU10 | 1 | 0.54 | -45.8 | 0.96 | 0.51 | -46.41 | 0.72 | 0.36 | -50.24 |
| DMU11 | 0.78 | 0.34 | -56.72 | 1 | 0.33 | -67.05 | 1 | 0.39 | -60.92 |
| DMU12 | 0.93 | 0.72 | -22.56 | 0.7 | 0.48 | -31.12 | 0.52 | 0.4 | -22.56 |
| DMU13 | 0.93 | 0.51 | -45.46 | 0.77 | 0.35 | -54.21 | 0.58 | 0.31 | -45.46 |
| DMU14 | 0.64 | 0.64 | 0 | 0.6 | 0.6 | 0 | 0.42 | 0.42 | 0 |
| DMU15 | 0.75 | 0.49 | -34.61 | 0.48 | 0.38 | -21.51 | 0.39 | 0.29 | -24.56 |
| DMU16 | 0.67 | 0.33 | -50.47 | 0.61 | 0.28 | -54.83 | 0.46 | 0.23 | -50.47 |
| DMU17 | 0.76 | 0.28 | -63.04 | 0.64 | 0.19 | -69.83 | 0.42 | 0.15 | -63.04 |
| DMU18 | 0.76 | 0.27 | -64.54 | 0.64 | 0.2 | -69.64 | 0.44 | 0.16 | -63.64 |
| DMU19 | 0.71 | 0.33 | -52.88 | 0.61 | 0.29 | -53.51 | 0.68 | 0.32 | -52.88 |
| DMU20 | 0.56 | 0.44 | -21.81 | 0.51 | 0.3 | -41.78 | 0.38 | 0.3 | -21.81 |
| DMU21 | 0.93 | 0.21 | -76.85 | 0.93 | 0.15 | -84.29 | 0.63 | 0.15 | -76.85 |
| DMU22 | 0.95 | 0.18 | -80.48 | 0.97 | 0.13 | -86.62 | 0.64 | 0.13 | -80.48 |
| DMU23 | 0.93 | 0.28 | -70.29 | 0.78 | 0.18 | -76.75 | 0.58 | 0.17 | -70.29 |
| DMU24 | 0.76 | 0.3 | -60.84 | 0.63 | 0.2 | -68.59 | 0.49 | 0.19 | -60.84 |
| DMU25 | 0.76 | 0.76 | 0 | 0.34 | 0.34 | 0 | 0.27 | 0.27 | 0 |
| DMU26 | 0.64 | 0.63 | -0.99 | 0.5 | 0.39 | -21.6 | 0.41 | 0.4 | -0.99 |
| DMU27 | 0.53 | 0.41 | -23.14 | 0.61 | 0.27 | -55.35 | 0.35 | 0.27 | -23.14 |
| DMU28 | 0.53 | 0.3 | -43.51 | 0.59 | 0.24 | -59.32 | 0.57 | 0.25 | -56.53 |
| DMU29 | 0.59 | 0.39 | -33.4 | 0.52 | 0.27 | -48.46 | 0.41 | 0.27 | -33.4 |
| DMU30 | 0.62 | 0.36 | -43.1 | 0.49 | 0.24 | -51.5 | 0.38 | 0.22 | -43.1 |
| DMU31 | 0.59 | 0.29 | -50.58 | 0.74 | 0.27 | -63.3 | 0.76 | 0.32 | -57.81 |
| DMU32 | 0.64 | 0.5 | -22.12 | 0.59 | 0.37 | -37.87 | 0.45 | 0.35 | -22.12 |

It can be seen in table 5.4, the target to be achieved in order to increase the efficiency of all the decision making units for the whole inputs, and also the percentages gain for the upgrade are shown in the table. For reaching the optimum efficiency of

DMU1 (January 2017) certain target has to be attained for the inputs, for input1 weight value (0.64 unit) has to be lowered by 0.16unit reaching 0.48 target, input2 weight value (0.71) by 0.3unit in reaching 0.41 target and input3 weight (0.64) by 0.16 in reaching 0.48, where all the targets were shown in the table above. Such targets are the minimum weight values that in the inputs weight can be reduced to in order to increase the efficiency for DMU1. The percentage gain for the DMUs (which is the percentage difference in lowering the input weight amount for the DMUs) were also automatically calculated by the PIM-DEA software and were also shown in the table 5.4, where can be seen that -24.96% gain for input1, -42.91% for input2 and -24.96% for input3 for DMU1. The negative sign (-) for the percentage (%) gain indicated the reduction of input amount in order to achieve higher efficiency or in other word, percentage gain having negative sign can also be called percentage loss of that particular input. At DMU2, the weight of input1 (0.67) has to be lowered by 0.2unit to reach the target 0.47 with -29.64% as its input gain, input2 of weight (0.47) to be lowered by 0.09unit to reach its target 0.38 having -19.61% as its percentage gain and 0.37 weight amount of input3 to be lowered by 0.08unit to reach its of target 0.29 with -20.52% as the percentage gain of that DMU. The target to be reached for the rest of the DMUs in reaching their optimal Efficiency is shown in the table above and their discussion is the same procedure as DMU1 and DMU2 discussed.

Since the idea behind reducing the input weight is to reach the optimum efficiency of a decision making unit, therefore the DMU with optimum efficiency supposed to have zero percentage (0%) for each of its input gain (no difference between the desired weight and the target weight amount) because the desired weight of all the inputs are already the optimal weights, for example; DMU6, DMU7, DMU14 and

DMU25 which were found to be in their optimum efficiency having 100% efficient each from table 5.1, Now such optimal efficiency of the DMUs mentioned were proved in table 5.4, where there is no difference between the desired inputs weight and the target inputs weight of such DMUs which is a good indication that the inputs weights are already the target amount.

The minimum negative number (highest) in the percentage gain of each input indicated that such input is closer to the efficient frontier line or hyper plan. It can be recall that DMU26 was the closest to efficient frontier hyper plan as discussed under table 5.1 above, which was found to be proved here in table 5.4 where the difference between their desired inputs and target inputs is small and minimum which resulted in their minimum negative percentage (highest percentage) in all the inputs for the DMU26.

Table 5.5: Target of CCR for output

| Name | output1 Value | output1 Target | output1 Gain(%) | output2 Value | output2 Target | output2 Gain(%) | output3 Value | output3 Target | output3 Gain(%) |
|---|---|---|---|---|---|---|---|---|---|
| DMU01 | 0.66 | 0.66 | 0 | 0.51 | 0.59 | 15.48 | 0.3 | 0.39 | 32.37 |
| DMU02 | 0.56 | 0.56 | 0 | 0.62 | 0.62 | 0 | 0.4 | 0.51 | 27.63 |
| DMU03 | 0.44 | 0.44 | 0 | 0.41 | 0.41 | 0 | 0.4 | 0.4 | 0 |
| DMU04 | 0.48 | 0.48 | 0 | 0.36 | 0.4 | 13.49 | 0.35 | 0.35 | 0 |
| DMU05 | 0.4 | 0.4 | 0 | 0.16 | 0.32 | 96.23 | 0.39 | 0.39 | 0 |
| DMU06 | 0.74 | 0.74 | 0 | 0.67 | 0.67 | 0 | 0.89 | 0.89 | 0 |
| DMU07 | 0.71 | 0.71 | 0 | 0.75 | 0.75 | 0 | 0.42 | 0.42 | 0 |
| DMU08 | 0.59 | 0.59 | 0 | 0.67 | 0.67 | 0 | 0.28 | 0.5 | 76.95 |
| DMU09 | 0.55 | 0.55 | 0 | 0.5 | 0.5 | 0 | 0.26 | 0.32 | 23.52 |
| DMU10 | 0.55 | 0.62 | 14.18 | 0.85 | 0.85 | 0 | 0.22 | 0.35 | 56.88 |
| DMU11 | 0.46 | 0.46 | 0 | 0.5 | 0.5 | 0 | 0.24 | 0.27 | 15.29 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DMU12 | 0.87 | 0.87 | 0 | 0.61 | 0.75 | 23.8 | 1 | 1 | 0 |
| DMU13 | 0.65 | 0.65 | 0 | 0.51 | 0.51 | 0 | 0.28 | 0.39 | 35.72 |
| DMU14 | 0.73 | 0.73 | 0 | 1 | 1 | 0 | 0.41 | 0.41 | 0 |
| DMU15 | 0.58 | 0.58 | 0 | 0.6 | 0.6 | 0 | 0.44 | 0.57 | 30.33 |
| DMU16 | 0.37 | 0.4 | 8.71 | 0.45 | 0.45 | 0 | 0.34 | 0.34 | 0 |
| DMU17 | 0.35 | 0.35 | 0 | 0.29 | 0.29 | 0 | 0.32 | 0.32 | 0 |
| DMU18 | 0.31 | 0.32 | 3.07 | 0.31 | 0.31 | 0 | 0.36 | 0.36 | 0 |
| DMU19 | 0.44 | 0.44 | 0 | 0.31 | 0.43 | 39.3 | 0.34 | 0.34 | 0 |
| DMU20 | 0.58 | 0.58 | 0 | 0.37 | 0.43 | 16.34 | 0.44 | 0.44 | 0 |
| DMU21 | 0.28 | 0.28 | 0 | 0.18 | 0.21 | 18.47 | 0.22 | 0.22 | 0 |
| DMU22 | 0.24 | 0.24 | 0 | 0.19 | 0.19 | 0.98 | 0.21 | 0.21 | 0 |
| DMU23 | 0.35 | 0.35 | 0 | 0.26 | 0.26 | 3.21 | 0.3 | 0.3 | 0 |
| DMU24 | 0.39 | 0.39 | 0 | 0.22 | 0.28 | 26.7 | 0.31 | 0.31 | 0 |
| DMU25 | 1 | 1 | 0 | 0.41 | 0.41 | 0 | 0.61 | 0.61 | 0 |
| DMU26 | 0.85 | 0.85 | 0 | 0.51 | 0.53 | 4.34 | 0.42 | 0.51 | 23.37 |
| DMU27 | 0.53 | 0.53 | 0 | 0.38 | 0.39 | 3.51 | 0.41 | 0.41 | 0 |
| DMU28 | 0.39 | 0.39 | 0 | 0.27 | 0.37 | 37.82 | 0.36 | 0.36 | 0 |
| DMU29 | 0.51 | 0.51 | 0 | 0.37 | 0.39 | 5.69 | 0.4 | 0.4 | 0 |
| DMU30 | 0.45 | 0.45 | 0 | 0.29 | 0.35 | 20.01 | 0.41 | 0.41 | 0 |
| DMU31 | 0.4 | 0.4 | 0 | 0.38 | 0.41 | 6.9 | 0.27 | 0.27 | 0 |
| DMU32 | 0.64 | 0.64 | 0 | 0.55 | 0.55 | 0 | 0.42 | 0.42 | 0 |

Table 5.5 shows the target to be reached for each of the output for upgrading the efficiency of each of the thirty two DMUs. It can be seen from the table at DMU1 that, output1 is already in its target point since the desired weight is the same as the target weight and it obviously emerged zero percent gain, output2 was closed to the target weight with 0.08 difference that emerged 15.48% of the output gain to contribute in upgrading the efficiency of DMU1 to optimum, and output3 with 32.37% gain with 0.09 difference between its actual weight and the target to be reached. DMU1 to DMU9 has the output1 weight reached its target weight also with

DMU11 to DMU15, DMU17 and DMU19 to DMU32. In the case of output2 DMU2 to DMU3, DMU6 to DMU11, DMU13 to DMU18, DMU11, DMU13 to DMU18, DMU25 and DMU31 has their output2 weight reached its target weight for the DMUs optimum efficiency. And output3 reached its target for the following; DMU3 to DMU7, DMU12, DMU14, DMU16 to DMU25, DMU27 to DMU32.So it can be seen that most of the output weight amount reached their target weight in optimizing the efficiency of the decision making units. The positive sign for the outputs gain target means that weight should be added to the output weight to reach the target that will contribute in the efficiency upgrade of the DMUs.

Since most of the outputs variables in table 5.5 reached their target in maximizing the efficiency of the DMUs, Figure 5.4 shows the number of DMUs whose output reached maximum weight target in reaching the optimal efficiency of the DMUs. It is indicated in figure 5.4 that 29 DMUs already have their output (output1) reached its maximum weight value in optimizing the efficiency of the DMUs, also 16 DMUs for output2 and 23 DMUs for output3. Alternatively, in optimizing the efficiency of the 29 DMUs shown in the figure output1 weight cannot be further adjusted in such DMUs but only for the remaining DMUs (DMU10, DMU16 and DMU18) for the output1that would need to gain more weight to reach its output target. In the case of output2, 16 DMUs would not expect any of their output2 weight adjustment but the rest of the 16 DMUs would expect. And for output 3, 23 DMUs are satisfied with the output3 weight but the remaining 9 DMUs need more weight to reach their target. The percentage of each DMUs that were satisfied with their output weight were shown in figure 5.5 below, where it can be seen that 90.63% of DMUs would need any further increase of weight from output1, 50% of DMUs would not to gain more weight of output2, and for output3, 71.88% of its DMUs were satisfied with their output3.

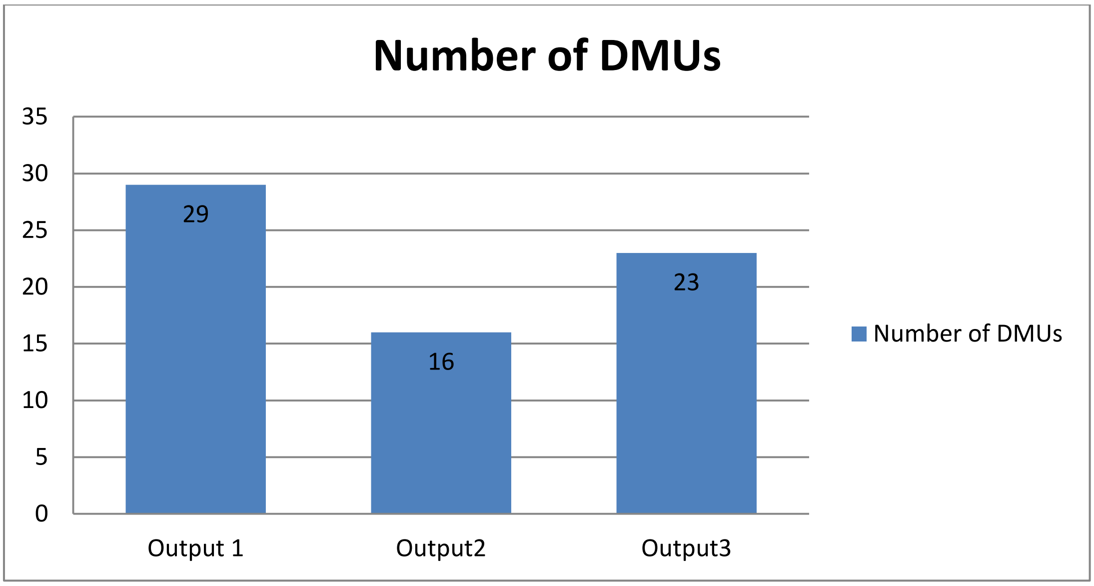


Figure 5.5: Number of DMUs that their output weight amount reached target

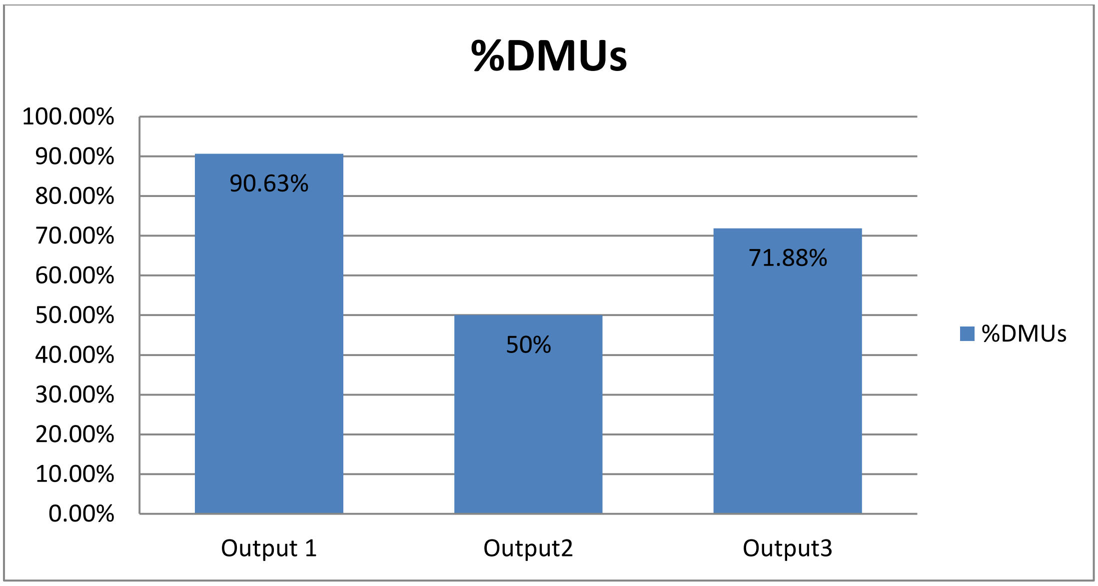


Figure 5.6: percentage of DMUs that their output weight amount reached target

# Chapter 6

# CONCLUSION, RECOMMENDATION AND SUGGESTION

In this section of the research, the efficiency of a chemical company's production process is evaluated by considering some environmental factors (such as chemical waste disposal from the company, Nylons disposal and cartons waste) given the growing requirements of environmental sustainability in the world. Data envelopment analysis technique was used in analyzing the data, and conclusion was made based on the results obtained using CCR model as the methodology in analyzing the data received from the company.

## 6.1 Conclusion

Due to the growth of technology in the 21$^{st}$ century that proportionally results in high waste disposal from discarded electric devices, discharge of multiple forms of waste from industries and other forms of waste due to human activity. Some of these waste disposals are potential threats to human life and also causes the risk of environmental hazard, this growth in technology proportionally increases the exposure of environmental hazard, the aforementioned issues were discussed in chapter 2 based on the findings made by researchers, Researchers made some findings on the practical Applications of Data envelopment analysis which is the method used in this research was also discussed in the chapter 2. The basic concept of the mentioned method used in this research was explained in chapter 3, where the data received from the Multi-products service of chemical processing company was tabulated and also the procedure followed in quantifying and receiving each of the variables data was explained in chapter 4. The data received in this research was solved by PIM-DEA software based on CCR model used as a methodology which is one of the Data envelopment analysis techniques, and also the analysis of the results were made in the previous chapter (chapter 5).

Based on the data results presented in chapter 5; the result from table 5.1 obtained shows the production process's efficiencies of every month (DMUs) from January 2017 till August 2019 as the months having the lowest waste disposal or lowest energy consumption, and are the DMUs with the highest efficiency shown in the table, whose are DMU6 (June, 2017), DMU7 (July, 2017), DMU14 (February, 2018) and DMU25 (January, 2019). These months with the optimum efficiency serves as a benchmark for the rest of the months in reducing the waste disposal and energy consumption of the production process for the chemical plant, this benchmark was shown in table 5.2. There is a best benchmark considered in lowering the waste disposal or energy consumption in every DMU, such best benchmarks considered for the individual DMUs were shown in table 5.2.1. The importance of each of the input and output variable and their weights amount contributed in the DMUs efficiency evaluation of the company shown in table 5.3, the target for each of the input and output in optimizing the efficiency of each month production process shown and discussed in table 5.4 and table 5.5. It can be concluded that the minimum waste disposal and energy consumption for the referenced chemical company found to be in June 2017, July 2017, February 2018 and January 2019. `Based on the amount of waste disposed and energy consumption in the months having the optimum efficiency, the researcher can also conclude that the maximum amount of monthly waste disposal that the company should not exceed in order to minimize its waste disposal and energy Consumption, without affecting the production Capacity, here the researcher was trying to use the values in table 6.1 below as a maximum limit that the waste and energy consumption should be considered every month in order to minimizes waste disposal which will definitely minimizes environmental hazard and the effect on climate change.

Table 6.1: Monthly tolerance amount of waste disposal and energy consumption

| Variables | Tolerance amount |
|---|---|
| Nylon | 50 (kg) |
| Carton | 65 (kg) |
| Washed Chemicals | 15 (kg) |
| Energy consumption (electricity) | 5500 (kw) |

## 6.2 Recommendation and Suggestions

Since the major concern of this research is to minimize the potential threat caused to environmental hazard by considering the negative products (waste) produced by the referenced industry, the following suggestions were made to ensure the environmental safety. Nylon waste and carton waste are the solid waste considered in the research and are disposes out from the industry to the waste storage field, where the environmental cleaners employed by government would later pack such wastes and disposes them somewhere. With this, the researcher recommended another research on how to analyze and do findings on the environmental effect of the technique uses by the government on handling the waste. Nylon waste can be minimized by reusing process, where the used nylons should be taken back to the plastic industry and reuse when sending other plastics instead of using new nylons which would contribute more waste.

In the case of the liquid waste sourced from washed chemicals, a policy should be made in the company to ensure that all the sample products are taken back to the main production reactors/mixers. Different reservoirs for different waste should be provided to be channeling each product (chemicals) waste and reuse the waste during its related production.

Government has to make a provision of compulsory subject/course to schools right from primary level to university level such subject/course should contain the kind and effect of harmful waste to human and environment and ways to overcome such problems. A policy should be made by government on the amount of waste allowed to be disposed by industries. Industries need to be restructuring their production process to make sure the reduction of waste disposal.

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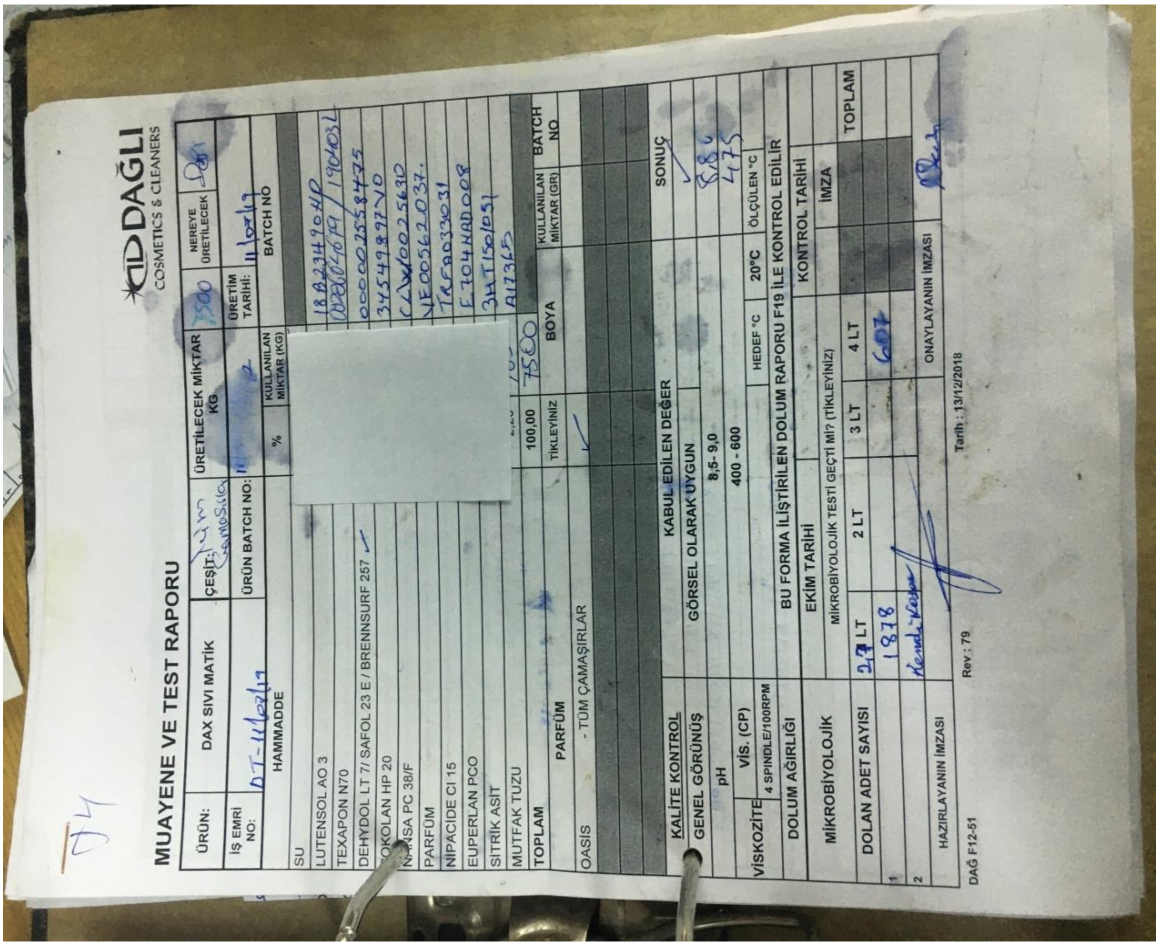
# APPENDIX

## Sample of Nylon and carton waste

## Water flour meter and charged water record book

## Dax product's receipt front page



DAĞLI
COSMETICS & CLEANERS

MUAYENE VE TEST RAPORU

| | | | | | |
|---|---|---|---|---|---|
| ÜRÜN: | DAX SIVI MATİK | ÇEŞİT: Tüm Çamaşırlar | ÜRETİLECEK MİKTAR KG | 7500 | NEREYE ÜRETİLECEK: Dağlı |
| İŞ EMRİ NO: | DT-11/02/19 | ÜRÜN BATCH NO: | | ÜRETİM TARİHİ: | 11/02/19 |

| HAMMADDE | % | KULLANILAN MİKTAR (KG) | BATCH NO |
|---|---|---|---|
| SU | | | |
| LUTENSOL AO 3 | | | 18B23490HP |
| TEXAPON N70 | | | 0026046719 / 190403L |
| DEHYDOL LT 7/ SAFOL 23 E / BRENNSURF 257 | | | 0000025558475 |
| SOKOLAN HP 20 | | | 3454989700 |
| NANSA PC 38/F | | | CLW00025630 |
| PARFÜM | | | VE005620037. |
| NİPACİDE CI 15 | | | TRFA033031 |
| EUPERLAN PCO | | | E704HAD008 |
| SİTRİK ASİT | | | 3HT150/051 |
| MUTFAK TUZU | | | A17365 |
| TOPLAM | 100,00 | 7500 | |

| PARFÜM | TİKLEYİNİZ | BOYA | KULLANILAN MİKTAR (GR) | BATCH NO |
|---|---|---|---|---|
| OASİS - TÜM ÇAMAŞIRLAR | ✓ | | | |

| KALİTE KONTROL | KABUL EDİLEN DEĞER | SONUÇ |
|---|---|---|
| GENEL GÖRÜNÜŞ | GÖRSEL OLARAK UYGUN | ✓ |
| pH | 8,5- 9,0 | 8,86 |
| VİSKOZİTE VİS. (CP) 4 SPINDLE/100RPM | 400 - 600 | 475 |
| | HEDEF °C 20ºC | ÖLÇÜLEN °C |

DOLUM AĞIRLIĞI: BU FORMA İLİŞTİRİLEN DOLUM RAPORU F19 İLE KONTROL EDİLİR

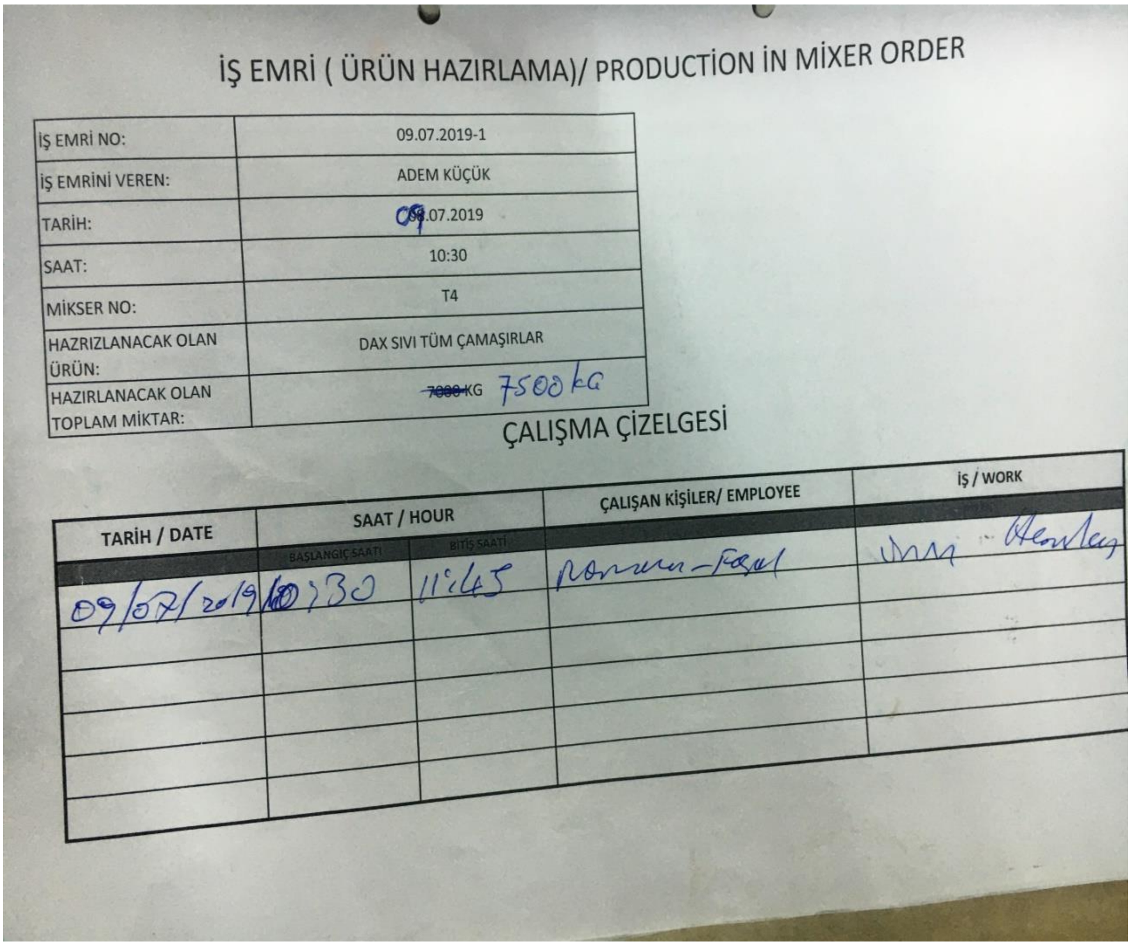
MİKROBİYOLOJİK: EKİM TARİHİ / KONTROL TARİHİ / MİKROBİYOLOJİK TESTİ GEÇTİ Mİ? (TİKLEYİNİZ) / İMZA

| DOLAN ADET SAYISI | 2,7 LT | 2 LT | 3 LT | 4 LT | TOPLAM |
|---|---|---|---|---|---|
| 1 | 1878 | | | 607 | |
| 2 | | | | | |

HAZIRLAYANIN İMZASI: Kendi Kaşe
ONAYLAYANIN İMZASI

DAĞ F12-51 Rev : 79 Tarih : 13/12/2018

## Dax product’s receipt back page



İŞ EMRİ ( ÜRÜN HAZIRLAMA)/ PRODUCTİON İN MİXER ORDER

| | |
|---|---|
| İŞ EMRİ NO: | 09.07.2019-1 |
| İŞ EMRİNİ VEREN: | ADEM KÜÇÜK |
| TARİH: | 09.07.2019 |
| SAAT: | 10:30 |
| MİKSER NO: | T4 |
| HAZRIZLANACAK OLAN ÜRÜN: | DAX SIVI TÜM ÇAMAŞIRLAR |
| HAZIRLANACAK OLAN TOPLAM MİKTAR: | ~~7000~~ KG 7500 kg |

ÇALIŞMA ÇİZELGESİ

| TARİH / DATE | SAAT / HOUR | | ÇALIŞAN KİŞİLER/ EMPLOYEE | İŞ / WORK |
|---|---|---|---|---|
| | BAŞLANGIÇ SAATİ | BİTİŞ SAATİ | | |
| 09/07/2019 | 10:30 | 11:45 | [illegible] | [illegible] |
| | | | | |
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| | | | | |
| | | | | |
| | | | | |