2011-01-01

A Framework For Strategic Sustainable Supply Chain Design

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A FRAMEWORK FOR STRATEGIC SUSTAINABLE SUPPLY CHAIN DESIGN

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Dedication

To my mother Maria Concepcion Armendariz and my husband Juan Carlos Franco for their understanding & immeasurable love.

A FRAMEWORK FOR STRATEGIC SUSTAINABLE SUPPLY CHAIN DESIGN

by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Industrial, Manufacturing, & System Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

December 2011

Acknowledgements

The success of any project depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this project.

I'd like to express my gratitude to my supervisor, Assoc. Prof. Ph.D., Jose F. Espiritu Nolasco, who was abundantly helpful and offered invaluable assistance, support and guidance. Deepest gratitude are also due to other of the members of the supervisory committee, Assoc. Prof. Heidi A. Taboada Jimenez without her vastly knowledge and assistance in sustainability this study would not have been successful.

Special thanks also to all my graduate friends, especially group members; Sandra Velador, Carlos Ituarte, Flor Gallegos, Oswaldo Aguirre, Karla Gutierrez and Claudia Valles for sharing the literature and invaluable assistance and who always have been there.

Finally, I would like to express my love to my family and my beloved husband; for their understanding & immeasurable love, through the duration of my studies.

Abstract

Sustainable supply chain management has raised interest considerably in recent years; due to environmental concerns from society as well industries. There is a high interest in the industries to solve this problem but many of the frameworks are directed to specific situation or structure. A strategic sustainable supply chain design framework is presented with the purpose of providing many companies, including small and big industries, the means to maintain an eco-friendly operation. These include; industry plants, distribution centers, and retailers.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Companies' responsive practices have been increasing in popularity due to the environmental concerns from society. Lately, many have increased their role in decisions related to green supply chain. The main aspect of why the attention has been focused on green Supply Chain framework was described by Lambert (Lambert, 2001) and Lamming (Lamming, 1998). Since a supply chain describes the network of suppliers, distributors, and consumers; when an amount of pollution is generated, it needs to be easily tracked in an existing network, this makes it easier for the companies to make a significant impact on the environment, by tracking the emissions generated to the environment. Industries view many of these environmental programs as possible alternatives for gaining or maintaining a competitive advantage by establishing a reputation. As well conscious of the effect they may have to the ecosystem the companies need to be logistically structured. This thesis is an effort to incorporate environmental considerations into decision-making processes by providing a framework that is intended to help companies adopt sustainable emerging practices. A four-step decision framework based on the system Plan-Do-Check-Act cycle (PDCA) is presented as a guide for the primary strategic and operational elements of a green supply chain.

CO_2 gases are responsible for the greenhouse effect, and as a consequence of global warming. Major releases of CO_2 concentrations came from industries. Lack of appropriate procedures to reduce the emission of Carbon gases, is the reason why the planet is facing climate changes. An appropriate disposal of residuals and preventive actions of environmental damage in their supply and production process, will contribute to reduce the irreversible damage that has been made to our atmosphere. A way to help the industries in this task is through Green Supply Chain.

This allows industries to take a look into its process procedures and to identify the areas were emissions could be reduced. As previously mentioned, the PDCA framework applies to the Green Supply Chain since the subtraction of raw materials, the internal production processes, up to the delivery of a final product and the adequate manage of its waste. Reducing waste, optimizing resources, selecting adequate transportation, operational procedures, satisfactory selection of packaging and raw materials, are some of the aspects where industries can improve. To understand more of the PDCA framework in a green supply chain, it is important to discuss some important aspects these will be discussed in the following chapters.

In chapter two, the main concepts as global warming will be explained, as well as the definition and some of the effects that have been presenting in the past years. As well as the principal cause that is the green house effect and the main green houses, as well the principal standards that have been establish to try to reduce the emissions of industries of these to the atmosphere.

In chapter three, the Life Cycle Analysis will be detailed, that is the examination of the product from beginning to end. Also, it will cover what type of emissions can be obtained from these studies (e.g. Global warming, Eutrophication,). Finally, in this chapter the boundaries that exist to make this study will be also explained.

In chapter four, the green supply chain will be described, and also the traditional supply chain. These would be explained starting the measures to know the efficiency of this and the structure of each one.

In chapter five, the proposed framework will be covered. Also, the structure of this and the steps that are needed in order to obtain a better solution are explained in detail.

Chapter six will show how the PDCA framework would be applied to a supply chain problem in order to understand how this framework will address different problems of suppliers. In this case, the problem to solve is the production of aluminum, taking into consideration two functions: cost and emissions. Every step of the application of the PDCA would be explained, starting from the acquisition of the data, some of the decision variables, the methodology, and how it was solved using Lingo.

Chapter seven will show this paper's conclusion of when the PDCA is used, this provides a useful controlled problem solving process. It is particularly effective for: implementing continuous improvement approaches, when the cycle is repeated again and again as new areas for improvement are sought and solved.

Chapter 2: Global Warming

It's visible in magazines (Mazur and Lee, 1993) that there are changes occurring in our planet: how the sea levels are rising more each year; Artic ice melting, leaving polar bears suffering from this sea-ice loss; coral reefs are disappearing due to their sensitivity to changes in water temperature; and finally, how the planet's temperature is rising more and more each year. All of these changes are related to one of the most frequent topics in society called global warming.

The Environmental Protection Agency (EPA) defined as an average increase in temperatures near the Earth's surface and in the lowest layer of the atmosphere, called troposphere. Global warming is caused by various factors both natural and human-induced (e.g., increased emissions of greenhouse gases from human activities). This temperature increases in the Earth's atmosphere, and contributes to changes in global climate patterns. Our earth has suffered a change in temperatures. This variation has brought visible interest from different sources, starting from government departments and scientists to investigate anything related with global warming to comprehend what is causing these changes and what possible outcomes this would bring.

An illustration of this awareness trend is the United Nations, which formed a group of scientists called the Intergovernmental Panel on Climate Change, or IPCC (IPCC, 2004). The IPCC meets every few years to review the latest scientific findings and write a report summarizing all that is known about global warming. Each report represents a consensus, or agreement, among hundreds of leading scientists. A noticeable example of these studies took place in (Solomon, Qin, Chen, & Marquis, 2007); the IPCC showed on the Fourth Assessment Report how our planet is suffering from changes as part of the global warming. This indicates

that the global average temperature since 1900 has risen by about 1.5ºF. By 2100, it is projected to rise another 2 to 11.5ºF. The ranges of these estimates arise from the use of models with differing sensitivity to greenhouse gas concentrations.

But not only have the United Nations obtained this type of data, also each government in the world has established departments according to their type of population and industries. United States also has agencies in charge of providing detailed information about greenhouse gas emissions, science, effects of climate change and what society can do to make an impact. The Environmental Protection Agency (EPA), U.S. Climate Change Science Program (CCSP), U.S. Global Change Research Program (USGCRP) are some of the most notable. A report made by USGCRP shows that the U.S. average temperature has risen by a comparable amount at a 1.3% and is very likely to rise more than the global average over this century, with variation from north to south countries.

In order to understand more about global warming, not only is it important to understand the definition, and how it has gained interest from governments and environmental departments, but it is also important to know the effects and how this is affecting our planet is important to review some of the effects that are occurring, this will be presented in the next section.

2.1 EFFECTS

As previously mentioned, the temperature of our planet is rising because of the greenhouse effect. According to the National Oceanic and Atmospheric Administration (NOAA), the global temperature record shows an average warming of about 1.3°F over the past century (Figure 1).

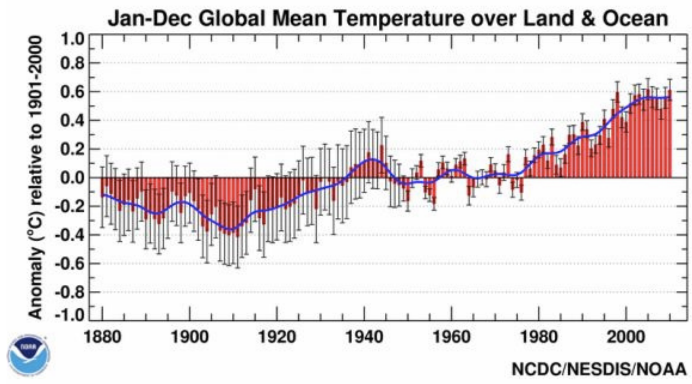

Figure 1 : Annual global surface temperatures from 1901-2000 averages for the period 1880-2007. Source: NOAA, 2010

As the graph shows, seven of the eight warmest years on record have occurred since 2001(NOAA, 2010). Within the past 30 years, the rate of warming across the globe has been approximately three times greater than the rate over the last 100 years. These include increases in air and water temperatures, reduced frost days, increased frequency and intensity of heavy downpours, a rise in sea level, and reduced snow cover, glaciers, permafrost, and sea ice. Making the last one especially pronounced across Alaska, Canada, Mongolia, and most of Russia and Europe.

According with the National Aeronautics and Space Administration (NASA); since satellite observations started in 1979, the September sea-ice extent has declined by 12% per decade, and the past 5 years have marked the lowest on record. The ice cover is thinning (bottom, left), making it more vulnerable to warmer temperatures. Forecasts by climate models (bottom, right) suggest that summer sea ice will largely disappear in the second half of the century, but the current rate of ice loss exceeds the models' forecasts, suggesting that ice-free conditions could arrive sooner than expected.

Figure 2 : Sea ice 1979-2007 average. Source; Artic Council,2004

The accelerated melting loss of ice is the cause of the sea level rising. There is strong evidence that the global sea level is currently raising at an increased rate of .37, 126 inch. A warming global climate will cause further sea level rise over this century as is portrayed by GCCIC (Figure 2). During the past 50 years, sea level has risen up to 8 inches or more along some coastal areas of the United States, and has decreased in other locations. The amount of relative sea-level rise experienced along different parts of the U.S. coast depends on the changes in elevation of the land that occurred as a result of subsidence (sinking) or uplift (rising), as well as increases in global sea level due to warming.

(Figure 3) Observed changes in relative sea level from 1958 to 2008 for locations on the U.S. Coast. Some areas along the Atlantic and Gulf Coasts saw increases greater than 8 inches over the past 50 years.

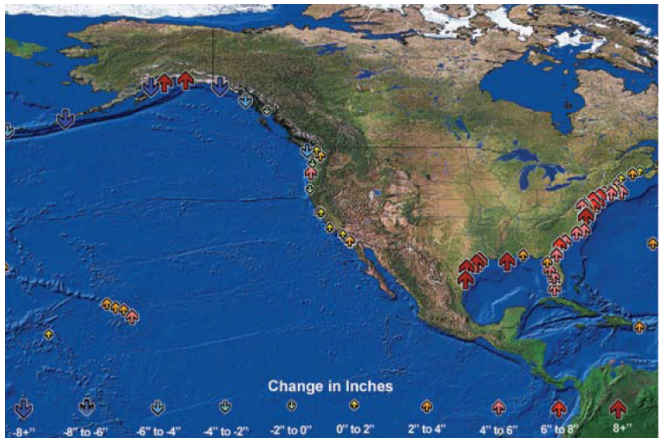

Figure 3: Sea level from 1958 to 2008 on the U.S. coast. Source: zervas, 2001,

These climate-related changes are expected to continue while new ones develop. Likely future changes for the United States and surrounding coastal waters include more intense hurricanes with related increases in wind, rain, and storm surges (but not necessarily an increase in the number of these storms that make landfall), as well as drier conditions in the Southwest and Caribbean. These changes will affect human health, water supply, agriculture, coastal areas, and many other aspects of society and the natural environment.

2.2 GREENHOUSE EFFECT

Scientists have spent decades figuring out what is causing global warming. They've looked at the natural cycles and events that are known to influence climate, but the amount and pattern of warming that's been measured can't be explained by these factors alone. The only way to explain the pattern is to include the effect of greenhouse gases (GHGs) emitted by humans.

It is often to relate green house gases with global warming, but what people don't know is that this is a natural aspect of our planet earth, that helps to regulate the temperature of our planet. As show in the (Figure 4) when the Sun heats the Earth, some of this heat escapes back to

space. The rest of the heat, also known as infrared radiation, is trapped in the atmosphere by clouds and greenhouse gases, such as water vapor and carbon dioxide.

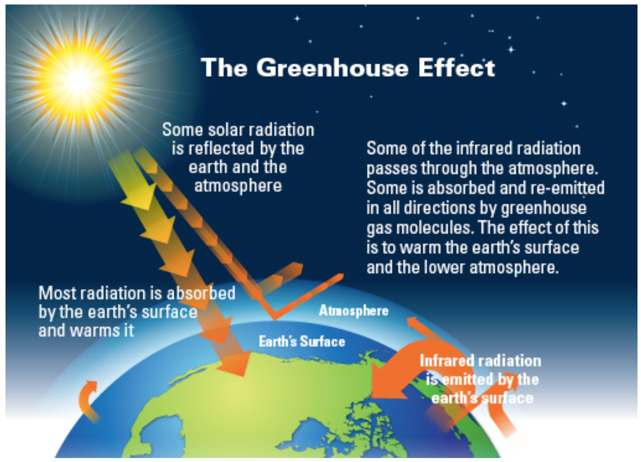

Figure 4: The greenhouse effect, Source: EPA, 2009.

Gutoswki one of the scientist of the U.S. Climate Change Science Program, Washington, DC (Gutowski, W.J, 2008) states that if all of these greenhouse gases were to suddenly disappear, our planet would be 60°F colder and would not support life as we know it. Human activities have enhanced the natural greenhouse effect by adding greenhouse gases to the atmosphere, very likely causing the Earth's average temperature to rise. Climate is influenced by a variety of factors, both human-induced and natural. In one of the reports made by the USCCSP, it is mention that the increase in the carbon dioxide concentration has been the principal factor causing warming over the past 50 years. Its concentration has been building up in the Earth's atmosphere since the beginning of the industrial era in the mid-1700s, primarily due to the burning of fossil fuels (coal, oil, and natural gas) and the clearing of forests. Human activities have also increased the emissions of other greenhouse gases, such as methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6).

As show in the (Figure 5) since 1750, atmospheric concentrations of CO2, CH4 and N2O have increased by over 36 percent, 148 percent and 18 percent, respectively. Scientists have concluded that this is due primarily to human activity. It is important to remark why the Carbon Dioxide, Methane and Nitrous Oxide are more relevant than other. An example could be that each of the green gases have different durations to affect in the environment, for example the ones with aerosol particles oscillate of how much time remain in the atmosphere usually it could be days or weeks. But, after the emission of carbon dioxide into the environment the atmospheric concentration remains elevated for thousands of years, and worse for methane this remains for decades. The climate effects of reductions in emissions of carbon dioxide and other long-lived gases do not become apparent for at least several decades. In contrast, emissions of short-lived compounds can have a rapid, but complex effect since the geographic patterns of their climatic influence and the resulting surface temperature responses are quite different even though the duration can be short. It is visible to understand these gases have developed an important influence part in the increase in temperature in our planet as is show in the (Figure 6).

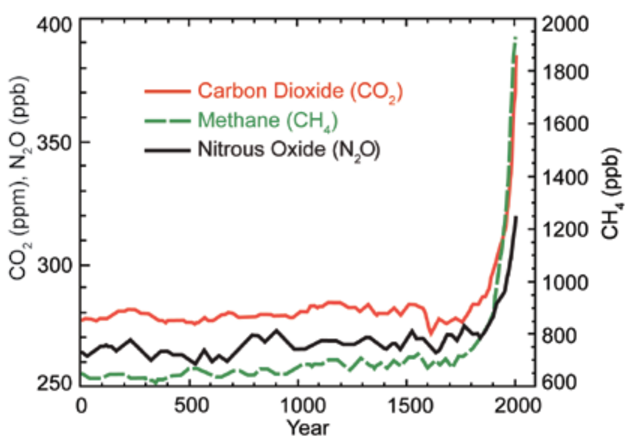

Figure 5: Concentrations of these gases since 1750.Source: Gutowski, W.J,2008.

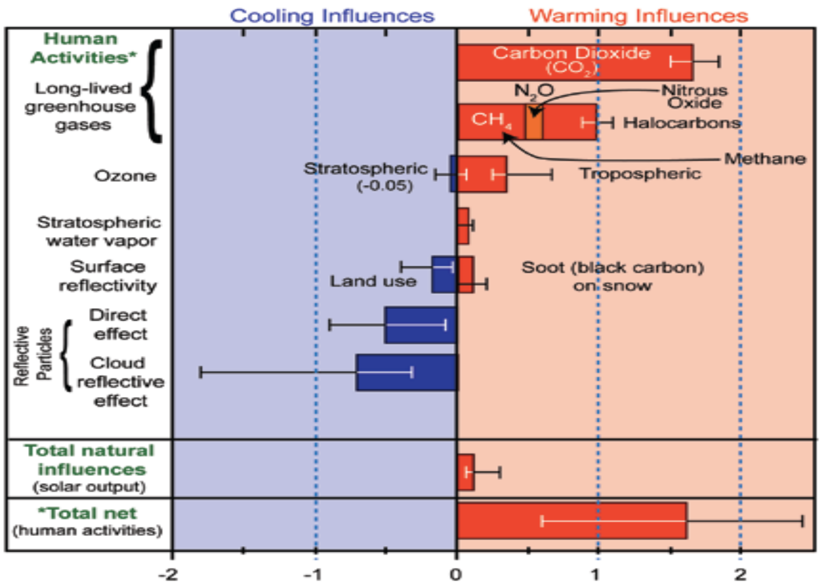

Figure 6: Different factors have had on Earth's climate. Source: Forster, P., 2007

As its visible, in the graphs the gas responsible for the most warming is carbon dioxide, also called CO2. Other contributors include methane released from landfills and agriculture (especially from the digestive systems of grazing animals), nitrous oxide from fertilizers, gases used for refrigeration and industrial processes, and the loss of forests that would otherwise store CO2.

Different greenhouse gases do not only have different duration to affect, but also heat-trapping abilities. Some of them can even trap more heat than CO2. A molecule of methane produces more than 20 times the warming of a molecule of CO2. Nitrous oxide is 300 times more powerful than CO2. Other gases, such as chlorofluorocarbons (which have been banned in much of the world because they also degrade the ozone layer), have heat-trapping potential thousands of times greater than CO2. But because their concentrations are much lower than CO2, none of these gases adds as much warmth to the atmosphere as CO2 does. To understand the effects of all the gases together, scientists tend to talk about all greenhouse gases in terms of the

equivalent amount of CO2. This was decided since 1990; the yearly emissions have gone up by about 6 billion metric tons of "carbon dioxide equivalent" worldwide, more than a 20 percent increase.

Another important characteristic of these gases is some of the effects that bring this to our atmosphere, the Carbon dioxide concentration is due to the use of fossil fuels in electricity generation, transportation, and industrial and household uses. It is also produced as a by-product during the manufacturing of cement. On the other side, Methane concentration is due mainly as a result of agriculture; raising livestock (which produce methane in their digestive tracts); mining, transportation, and use of certain fossil fuels; sewage; and decomposing garbage in landfills. At last, Nitrous oxide concentration is increasing as a result of fertilizer use and fossil fuel burning. The US Environmental Protection Agency (EPA) ranks the major greenhouse gas contributing end-user sectors (Figure 7) in the following order: industrial, transportation, residential, commercial and agricultural as the major sources of an individual's greenhouse gas include home heating and cooling, electricity consumption, and transportation.

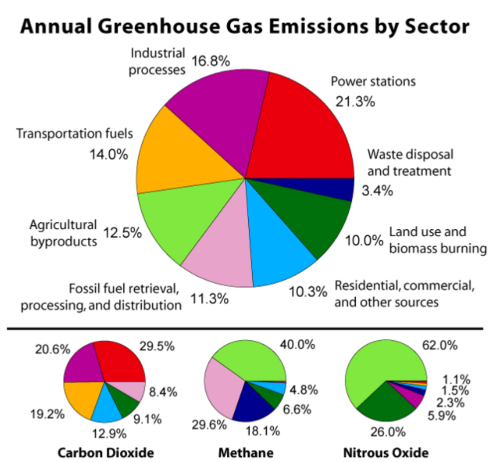

Figure 7: Global anthropogenic greenhouse gas emissions for the year 2000. Source: IPCC,2004.

Carbon dioxide, methane, nitrous oxide and three groups of fluorinated gases (sulfur hexafluoride, HFCs, and PFCs) are the major greenhouse gases, that for our investigation it will be attempted to reduce at lease a percentage .The two major percentages belong to industry and transportation, that as society knows these are also link with pollution, is why they have been subjected to different protocols and know to a new framework in order to be reduced.

2.3 ENVIRONMENTAL POLICIES

One of the principal contributors to the green house gases, are human activities. At this moment Governmental and environmental agencies not only start to investigate about his effect call global warming, but also to reduce the main gases that compose the green house effect. This will only be effective by implementing a set of rules this would be doing a reduction in certain activities to implement rules that will help to reduce the green house or the call global warming to reduce emissions, from the atmosphere. The primary international effort to prevent the climate change was coordinated by the UNFCCC (Mc Cright and Dunlap, 2003). The Kyoto Protocol is their only legally necessary emissions agreement and only limits emissions through the year 2012.Unfortunally Afghanistan and the USA are the only nations in the UNFCCC that have not ratified the original protocol, and as of October 2011 several others have refused to extend the emissions limits beyond 2012.

In United States, Under the Clean Air Act (CAA), (EPA, 2009) sets limits on certain air pollutants; including setting limits on how much can be in the air anywhere in the United States. The Clean Air Act also gives EPA the authority to limit emissions of air pollutants coming from sources like chemical plants, utilities, and steel mills. Individual states or tribes may have stronger air pollution laws, but they may not have weaker pollution limits than those set by EPA. This policy also mandates controls on air pollution from mobile sources by regulating both the

composition of fuels and emission-control components on motor vehicles and non-road engines. Vehicle fuel standards for gasoline and diesel are met by refiners/importers, and by other parties in the fuel distribution system. Regulation of vehicles includes vehicle emission limits for hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx), and particulates in the case of diesel vehicles. These limits, which must be met by the vehicle manufacturers, apply to on-road vehicles, off-road vehicles, and non-road sources (e.g., marine engines, locomotives, and lawn and garden equipment). Under the 1990 CAA amendments, vehicle standards are being made more stringent, in stages, through 2005 or later.

Another Office of Environmental Review that is responsible for the National Environmental Policy Act (NEPA); was one of the first laws ever written that establishes a broad national framework for protecting our environment. France was the first to frame a national policy for the long-term management of radioactive material and waste. According to Hans Riotte, the OECD's nuclear energy agency, the Act providing for burying waste deep underground and setting a timetable for this "has put France clearly in the lead in Europe.

As it is evident, there are several rules have been put into practice to have a reduction in the contamination produce in the normal activities.

As policies were implemented in the sector of the industry, a group of members established certain standards to implement and improve the processes; this organization is called The International Organization for Standardization (ISO). The ISO is a nongovernmental organization that was established in 1947 for the purpose of developing worldwide standards, improving international communication and collaboration, and promoting the smooth and equitable growth of international trade Starting with a environmental focus.

2.4 ENVIRONMENTAL MANAGEMENT STANDARDS (ISO 14000 SERIES)

Industries have been point as the principal generator of pollution, as the society is growing, also the increasing demand for products is incrementing, and at the same time adding pressure on the environment. Exploitation of resources and manufacturing of products are creating potentially devastating stresses on the natural world. For this reason standards were created, to help in the creation of a product with the minimum damage to the environment. The International Organization for Standardization (ISO) has developed standards that help administrations to take a proactive approach to managing environmental issues.

ISO 14000 is a set of environmental management standards, which can be implemented in any type of organization in either public or private sectors from companies to administrations to public utilities. To mention some of the ISO 1400, five would be explained but only one would be put in practice for this research.

ISO 14001: has been adopted as a national standard by governments and encourage its use around the world.

ISO 14031: provides guidance on how an organization can evaluate its environmental performance. The standard also addresses the selection of suitable performance indicators, so that performance can be assessed against criteria set by management. This information can be used as a basis for internal and external reporting on environmental performance.

ISO 14040: Environmental management – Life cycle assessment – Principles and framework, provides a clear overview of the practice, applications and limitations of LCA to a broad range of potential users and stakeholders, including those with a limited knowledge of life cycle assessment.

ISO 14044:Environmental management – Life cycle assessment – Requirements and guidelines, is designed for the preparation of, conduct of, critical review of, and life cycle inventory analysis. It also provides guidance on the impact assessment phase of LCA and on the interpretation of LCA results, as well as the nature and quality of the data collected.

The only of these standards that is going to be used is the ISO14040 that would this would be apply to our framework due to the efficiency of find the problem in any stage of the production due to the LCA. Also, this standard will facilitate the process of evaluating the impacts that a product has on the environment over its entire life, thereby encouraging the efficient use of resources and decreasing liabilities. A life cycle assessment (LCA) is the assessment of the environmental impact of a given product throughout its lifespan. This will be explained in the next chapter.

Chapter 3: Life cycle Assesment

Traditionally, products were designed and developed without considering their impacts on the environment. The mayor factors considered in a product design include; function, quality, cost, ergonomics and safety. The only considerations to the environment where supervising the emissions in the manufacturing area the product. However, the emissions do not only occur in manufacturing area but also in the entire life of a product. Thus, there is a need for a systematic analytical tool for the environmental assessment of a products' entire life cycle. This tool is Life Cycle Assessment (LCA).

The goal of LCA is to compare the environmental performance of products in order to be able to choose the least pollutant and identify the most polluted process.

The term 'life cycle' refers to a complete assessment including the raw material production, manufacture, distribution use and disposal (including all intervening transportation steps). This then is the 'life cycle' of the product.

In these research the product to be taking in analysis is aluminum, due to extended analysis in the life cycle analysis to find the process with the biggest emissions.

In order to understand the LCA is important to understand first the term "life cycle" this refers to the major activities in the course of the product's from its raw material, to its final disposal, as is show in the (Figure 8) published by ISO (ISO, 2004) this illustrates the possible life cycle stages that can be considered in an LCA.

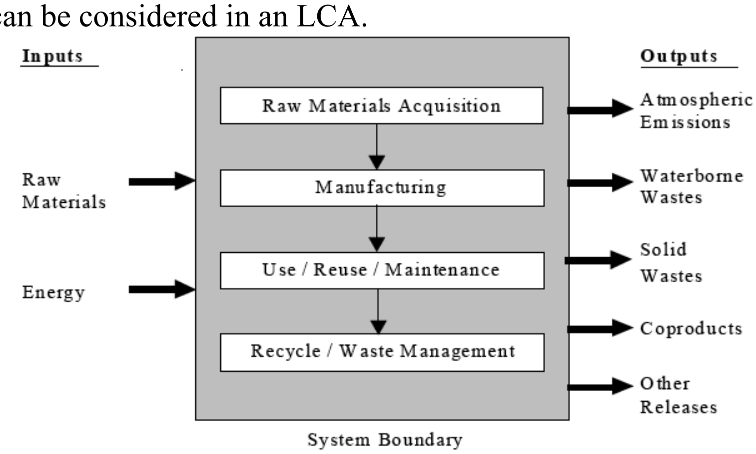

Figure 8: Life cycle stage. Source :ISO 1440.

The term life cycle includes the compilation and evaluation of the inputs and outputs and the potential impacts of a product or process throughout its life cycle. This is important to understand because for our research the inputs and outputs of each stage of our product in this case aluminum would be taken in consideration.

3.1 PHASES OF LIFE CYCLE ASSESMENT

Not only life cycle is the only step applies to our research likewise, it is important to follow the four components (or phases) of an LCA in order to obtain better results. These consist of the following: Goal and scope definition, Inventory analysis, Impact assessment and Interpretation as is illustrated by the ISO 14040 (Figure 9).

Goal and scoping definition, is the phase of the LCA process that defines the purpose of including life cycle environmental impacts into the decision-making process. Also this phase is going to show the boundaries to be review in the assessment, this will be explained in more detail in the next section.

Another phase is the inventory analysis this is in charge of identify and quantify energy, water and materials usages and the environmental release (e.g., air emission and solid waste disposal) as previously mention the inputs and output would be taken in consideration .The third phase is the impact assessment, this assesses the potential human and ecological effects of energy, water and material usage and the environmental releases identified at the end of the inventory analysis. The last page is the interpretation, this will evaluate the results of the inventory analysis and impact assessment to select the process or service.

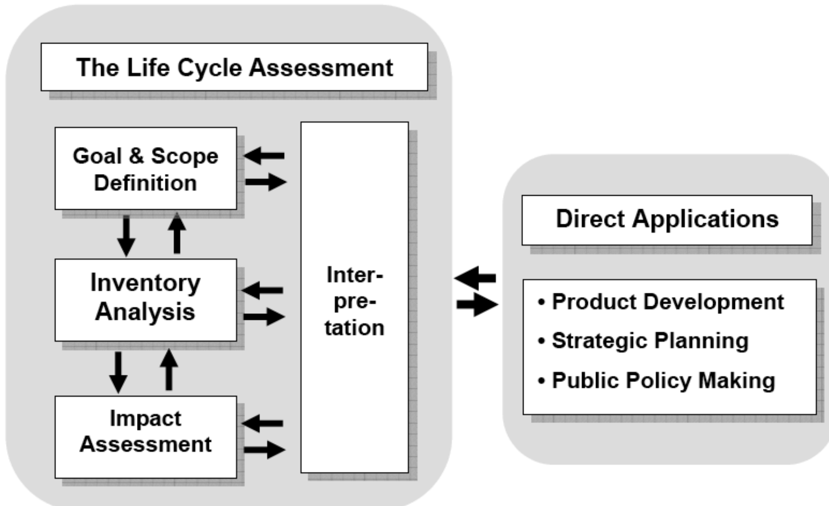

Figure 9: Phases of an LCA. Source: ISO 14040,1997)

3.1.1 Goal and scope definition

Goal definition and scoping is the phase of the LCA that defines the purpose and method of including life cycle environmental impacts into the decision-making process. In this phase, the following elements must be determined: the Goal and scope, the system function, System boundaries, Functional unit, Calculation unit and how the results should be interpreted and displayed in order to be meaningful and usable.

Goal: ***I***n this first step, the goal and scope of this study is to found the source of emissions input and out puts in the process and focus in that process. For our goal is going to be used an existing system of a supply chain, identifying the main environmental problems in the product or process life cycle, identifying opportunities for improving the existing system, comparing systems and their potential impacts, and selecting options prospectively.

Scope: ***T***he scope identifies the product system or process to be studied, the functions of the system, the functional unit, system boundaries, allocation procedures, impact categories, data requirements, and limitations.

System: ***F***irst step of a LCA study is the definition of a reference system, for which all the inputs and outputs will be recorded and the total environmental impacts of a product or

process will be determined. In a LCA study, the term "system" consists of a set of unit processes that are linked to one another by flows of intermediate products or wastes. In the system that these study pretend to analyze is important to include resources used and releases to air, water, and land. Dividing the product system into its component unit processes helps in the identification of the inputs and outputs of the product system. For example in the process of the aluminum production is important not only to take in consideration the main production but also to includes different subsystems, which are linked between themselves and the output of a subsystem is considered as an input for the next. The main point to study subsystems is determined by the data for each one. Subsystems contains the procedures of inputs and/or outputs acquisition, manufacture, transportation, recycling and final disposal. After the definition of the system and its subsystems, every subsystem is examined separately in order for all the inputs and outputs to be determined. When all this information is gathered, they are added, based on mass and energy balances, in order for the total environmental impact of the examined product or process to be estimated.

System boundaries: ***T***he determination of the system boundaries concerns the selection of the processes or units in sequence (subsystems) that will be included in the studied system; they must be always determined in accuracy and remain stable during the whole study. In addition, the boundaries of a study are drawn so as to include all relevant impacts. This would be explaining in more detail in the next section.

Functional unit: ***B***esides the system definition, an item that plays an important role in a LCA study and, for this reason must be clearly defined from the beginning, is the product functional unit. The term functional unit is referred to the machine type, which performs a specific process. The main target of a functional unit is to constitute a reference unit to which all the inputs and the outputs of the system will be referred. This reference unit is necessary in order to ensure the possibility of comparison between the results of a LCA study; the existence of a common base is essential in order to compare different systems.

Calculation Unit: *T*he calculation unit is the reference unit to which all the inputs and the outputs of the system will be referred. For example when the study refers to mining or metallurgical activities, the calculation unit is a specific quantity, for example 1 ton, of product.

3.1.2 Life Cycle Inventory

In the LCI phase, the data of our experiment is collected to quantify inputs and outputs of the aluminum system. The types of data include energy, raw materials, and other physical input; products, co-products, and wastes; releases to air, water, and soil; and other environmental aspects. All these data need to be consistent with the system boundaries defined in the goal scope and definitions is constructed for our purpose is going to be cradle to grave that is going to be explained in the next section. The model shows the activities in the system including processes, transportation, waste management and the input and output flows among them throughout the life cycle. Input and output data; raw materials, energy, products, solid waste, emissions to air and water (Figure 10) are collected for all the processes in the system. Calculations are then performed to estimate the total amounts of resources used and pollution emissions in relation to the functional unit. The results consist of an inventory of the environmental input and output data of the system being studied. Data can be presented in tabular or graphic form.

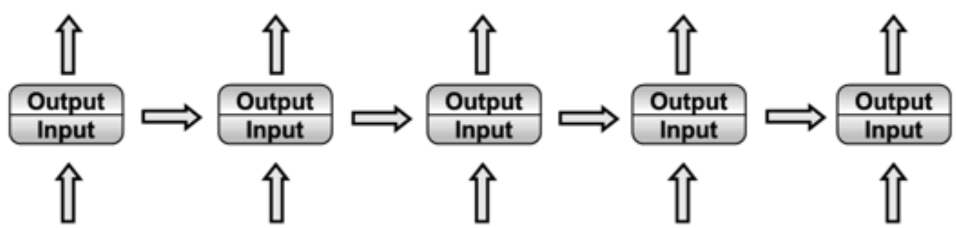

Figure 10: Activities of a system

3.1.3 Life Cycle Impact Assessment

This phase it is a quantitative asset that is characterize for the environmental Inventory Analysis. With the objective to understand their environmental importance and to estimate the possible environmental impacts which are related to the result of inputs and outputs. This is

going to be used for the identification of improvement plans, for the comparison between different systems based on selected indicators and for the localization of environmental issues, for which other techniques can give supplementary environmental data and useful information for this makers.

The life cycle impact assessment is obtained by following the next steps: Selection and Definition of Impact Categories, Classification, Characterization, Normalization, Grouping, Weighting, Evaluating and Reporting LCIA Results.

The first step it is called Selection and definition of impact categories. In these step it is important to select the impact categories that will be considered as part of the overall LCA. Some of the mayor impact categories show by the EPA report of 2006. It was determined during the scope development process that a comprehensive set of environmental impact categories were to be investigated. For the purposes of the study results, the following impact categories were determined to best represent the Aluminum process priorities in issues related to sustainability:

- Stratospheric Ozone Depletion (CFCS, HCFCS, CH3Br);
- Global Warming (e.g., CO2, NO2, CH4, CFC);
- Human Toxicity (formaldehyde, toluene, metals to air);
- Eco-toxicity (dioxins, PAH, PCB, metals, etc);
- Acidification (SO2, NOX, NH3);
- Eutrophication (PO4, NO, NO2, NH4);
- Land uses;
- Photochemical smog;
- Effects to the human health in the work place;
- Water Use;

The second step is classification, is to organize and combine the LCI Data into impact categories. For LCI items that contribute to only one impact category, the procedure is a

straightforward assignment. For example, carbon dioxide emissions can be classified into the global warming category or Sulfur Oxides can be classified into Acidification.

The environmental impact that would be selected for our study is the global warming this is selected due to the gases that are going to be evaluate (C02, N02, CH4) are found present in the aluminum supply chain system to be explore.

The third step is Characterization; this provides a way to directly compare the LCI results within each impact category. In other words, characterization factors translate different inventory inputs into directly comparable impact indicators. For example, as previously mention C02 is one that absorb more heat and even some of the green house gases are less or more than CO2 (e.g. Methane, nitrogen dioxide) it is easier to see their effect in the atmosphere by converting them into C02 equivalent or Global warming potential (GWP) in order to be able to compare with other gases.

An example of these could be how to identify with gas has more impact on global warming, counting with 14 pounds of Methane and 30 pound of chloroform are going to be transform into GWP. Using the Following the equation 1.1 Being the GWP factor of methane 21 and 9.

Inventory Data × Characterization Factor = Impact Indicators (eq.1)

Inputting in the inventory data the 30 pounds of Chloroform and in the characterization the GWP of 9 this would result in an impact indicator of 270 and for the Methane 294. The calculations show that 14 pounds of methane have a larger impact on global warming than twenty pounds of chloroform.

Once these steps have been followed optional elements can be apply these are: normalization, grouping, weighting, and data quality analysis.

3.1.4 Life Cycle Interpretation

The interpretation stage is a repeated and systematic process for the identification, description, estimation and presentation of all the information that have been derived from the other stages. The purpose of this stage is to analyze results, to give references and to lead to conclusions and recommendations that allow taking future decisions. It is a rational and systematic evaluation of the needs and opportunities to reduce environmental burdens, in terms of energy and material consumption and waste emissions by a product, process or activity. The final output of the analysis should be a set of improvement scenarios, which will help reduce the environmental burdens brought on by a product or process.

3.2 SYSTEM BOUNDARIES

An important part of the Goal and scope definition, are the system boundaries these are important because establish the limits of the system that is going to be analyze. For our study the process or system to be analyze is a distributor of aluminum starting from raw material though disposal or recycling. This life cycle is conformed by four phases: introduction, growth, maturity, and decline. This product life cycle is mention by some authors (De Benedetto) as a high impact framework method to aid the supply chain decisions. But, in reality very few products follow such a regulatory cycle. The length of each stage varies enormously and is not easy to tell witch stage the product is in. In order to have a more limited system where the stages of the product can be observed as previously mentioned according to the ISO 14040[9] standards, Life Cycle Assessment systems boundaries are of big help to the supply chain. These boundaries are conformed by four categories these are (Figure 11); (1) Cradle to grave, (2) Cradle to gate, (3) Gate to grave,(4) Gate to Gate. Cradle-to-grave is the full Life Cycle Assessment from manufacture ('cradle') to use phase and disposal phase ('grave'). Cradle-to-gate is an assessment of a partial product life cycle from manufacture ('cradle') to the factory gate. Cradle-to-cradle is a specific kind of cradle-to-grave assessment, where the end-of-life disposal step for the product is a recycling process. Gate-to-gate is a partial Life cycle Analysis looking at

process in the entire production chain. The main reason to point out the importance of the system boundaries is because the companies could distinguish in which stage they are producing more contamination to the environment, and change it. It is significant to mention that 'cradle to grave' is the boundary that is going to be used for the framework, the main reason is because is the one that is easy to apply to a supply chain that is most commonly used.

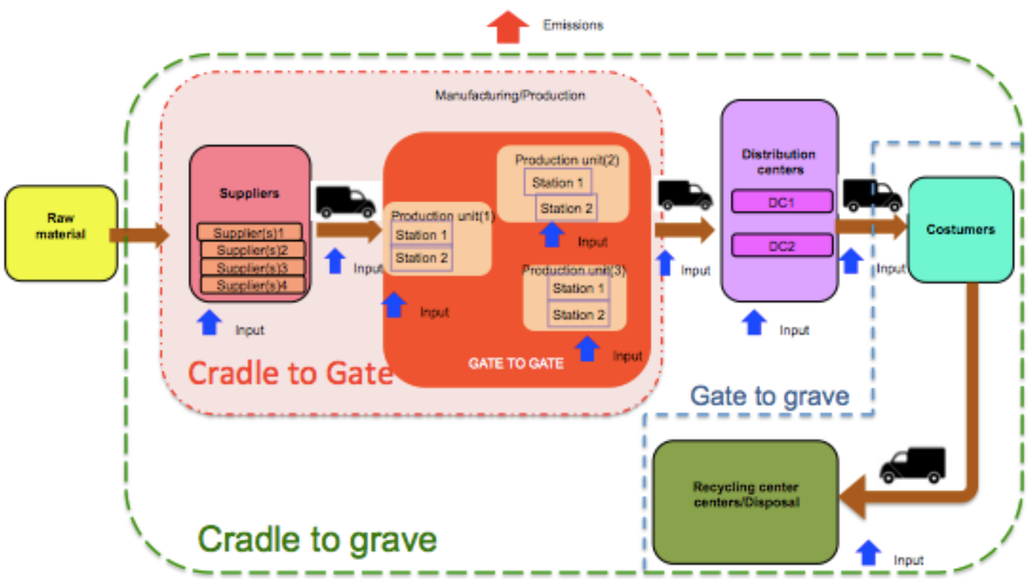

Figure 11: System boundaries.

Chapter 4: Sustainable Supply Chain

4.1 DEFINITION

There are numerous definitions of the terms 'Sustainable' and 'Supply Chain'. For the purposes of this framework, Brent Wollaston Griffins' states a practical definition Supply Chain Director is:

"A Sustainable supply chain is the relation of the management of raw materials and services from suppliers to manufacturers to customers where improvements of the social, economical and environmental impacts are explicitly considered."

A sustainable supply chain also is defined as a shared commitment to sustainable development via the three pillars: economic growth, environmental protection and social progress. An important relation between the customer to retailer and through manufactures was stated, but after several search in companies these positions have changed. For example, the emphasis has shifted from the 'green consumer' to the 'responsible retailer'. Thereby, the retailer or service provider and the brand owner assume responsibility for ensuring that consumers can buy products and services with confidence in their source and manufacture. This frequently demands the definition of life-cycle-based standards for the environmental and social performance of products, which are then implemented throughout the supply chain, this life cycle will be explain in detail in the paper.

Many industries believe that the option of an environmental friendly operation is usually with high cost or consuming time. But, by re-evaluating a company's supply chain, from purchasing, through distributing final products, many that have emphasis on improving environmental and social performance, has had real benefits. An example, show by Rivera (Rivera, 2001), shows the interest of customers and the companies to re-evaluate an improving sustainable supply chain is Shell's plants; this company plan by the mid 90's to dispose of the Brent Spar oil rig, and its alleged negative impacts on local communities in Nigeria, brought social and environmental responsibility to the world stage. Shell's journey towards sustainable development commenced with these wake-up calls and started at the top of the organization.

Since then, Shell reviews its sustainable strategy as part of its planning process and has moved from its initial ‘Trust me’ program to its current ‘Show me’ approach. Another example are the top 30 grocery retailers in Europe account for 67% of the total retail sales of Euro 865 billion, with the leading 10 European retailers representing 40% total retail sales.

As previously mentioned, companies have an important impact on the environment, especially with the correct decisions, this is why standards where created to help this industries trough the life cycle of the product. These standards are explained in the next section.

4.2 TRADITIONAL SUPPLY CHAIN

The traditional supply chain is defined as an integrated manufacturing process wherein raw materials are manufactured into final products, then delivered to customers (via distribution, retail, or both). (Figure 12) below illustrates the structure of the traditional supply chain.

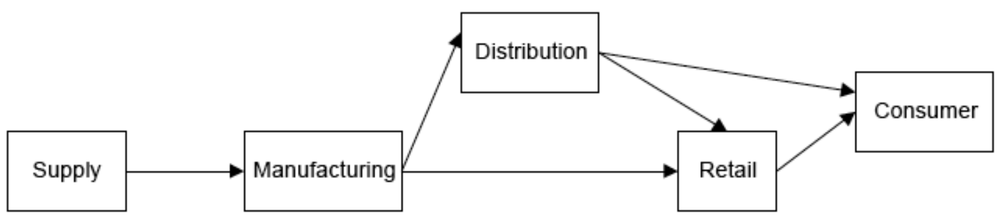

Figure 12: The traditional Supply chain

Design, modeling, and analysis of the traditional supply chain has primarily focused on optimizing the procurement of raw materials from suppliers and the distribution of products to customers. The issues considered within this scope of analysis include (Beamon, 1998):

• Production/Distribution Scheduling: Scheduling the manufacturing and/or distribution schedule.

• Inventory Levels: Determining the amount and location of every raw material, sub-assembly,and final assembly storage.

• Distribution Center (DC) - Customer Assignment: Determining which DC(s) will serve which customer(s).

• Plant - Product Assignment: Determining which plant(s) will manufacture which product(s).

• Buyer - Supplier Relationships: Determining and developing critical aspects of the buyer supplier relationship.

• Number of Product Types Held in Inventory: Determining the number of different product types that will be held in finished goods inventory.

4.3 STRUCTURE AND PERFORMANCE MEASUREMENT

The traditional performance measurement, available literature regarding traditional supply chain systems identifies a number of performance measures as important in the evaluation of supply chain effectiveness and efficiency. These measures are typically concerned with: (1) customer satisfaction, service, or responsiveness or (2) cost.

For a sustainable supply chain performance measures the traditional measures are inadequate in capturing the dual extended supply chain objectives of economic efficiency and environmental protection. This identifies a need to develop new, more inclusive, measures to describe supply chain performance. ISO 14000 identifies the need for these measures implicitly in its certification requirements. In fact, these certification requirements (as previously identified), refer directly to requiring environmental impact analysis and assessment, continuous measurement, targets, and monitoring procedures.

4.4 STRUCTURE OF A SUSTAINABLE SUPPLY SYSTEM

To understand the importance of the elements that will influence how the supply chain is to be managed, (either internally or externally) it is important to understand the structure of the cradle to grave in a supply chain. The major elements of the life cycle typically include procurement, production, and distribution. For our supply chain structure these is conform by; raw material, manufacturing, warehouse, transport, distribution center, utilization and finally disposal (see Figure 13). For our purpose we will exclude the raw material due the different

materials that are used for the industries. A good example of how each stage of a supply chain is important, can be seen in the inventory made by the environmental federal protection agency (EPA), where they determine the different percentage of that Green house gas emissions by sector.

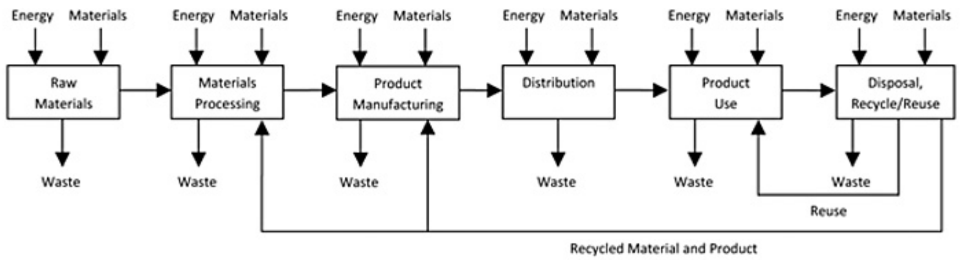

Figure 13: Sustainable supply chain structure

Manufacturing is the first step of a product; also is the phase more important that covers from the arrival of the raw material, the assembly of the product, through processing and manufacture. This stage in a sustainable supply chain is important due to the many factors that can affect the environment two examples of this are; first in the production of steel, a lot of water is wasted due to the constantly cleaning of the scrap material, and there is a significant amount of emissions to the air due to the constant torching of metals and the melt shop, this can not only bring problems to the environmental but also to the community, that live around. The waste created, amount of energy used, the water pollution, and emissions to air and land. The second example of how this stage is important is the waste of material that is not reused or recycled are; New Zealand, (Ioannis S. Arvanitoyannis, 2003) industries put 3.5 million tones of waste annually into its landfills, which equates to approximately one tone of lost potential resources for every New Zealander. Identifying ways to reuse products or their constituent parts is a challenge for all industry. As previous stated in the example the of manufacturing is that many of the emissions to the environmental are from this phase that not only affect the industry but also the community around and as stated in sustainability this is an significant factor besides the economy and environment (National Emissions Inventory, 1970-2006). Finally, once that the product is

manufactured it is transferred to the next phase; the warehouse is an important factor due to the sustainability issues are confronted for example; the energy use in the storage and packaging, as well the waste produce they used in order to storage and many of the times this finish in disposal rather than being recycled. In order to transfer the packaging to the distribution center different types of transportations are used. Transportation is a key element of the supply chain, for example McDonalds supply chain counts with three types of transportation, these are; road, air, and sea to distribute to the entire U.S chains. As it is known, the different types of fuel used for the industries in the U.S are consider to be approximate 14% of the green house emissions, which is why a good supply chain will help to reduce this types of problems to the environment. Distribution center is one of the last steps previous to the customer; this stage problem respecting sustainability would be; the types of materials used, the energy used and the type of picking optimization of the type of vehicle that is going to be choosing to deliver the customer. Once the product is delivered to the customer is where the time of the product differed, in the type of usage that of the product is intended to be used, as well if the product have a easy way to be recycled or disposed, but this depend many of the times in the companies (Figure 14). An example of a good industry that reuses the material that probably for the user is not good anymore is EcoWorx (JEFFERY, W, 1999) this company is in charge of producing quality carpets, but once that the carpets meet their requirement, the user have the option to return the product to the company in this way they can be reused as a raw material. Making not only to help the environment, but also a system that helps to reduce the cost of raw material.

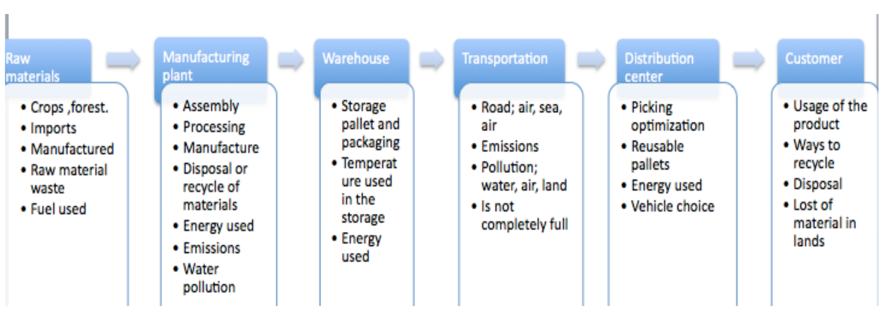

Figure 14: Structure of a supply chain cradle to grave.

Chapter 5: Sustainable Framework (PDCA)

The PDCA cycle will be influenced by the various stages that have been previously described in this paper. These relationships may vary due to assumptions made by the decision-maker, and the level of complexity that they wish to model. The sustainable development of supply chain is based on the social, environmental and economic impacts of these goods and services along the supply chain. The participating organizations may differ in product or service and are at varying stages of the supply chain. This paper have provided the stages that a product follow in the supply chain, in this section the steps of the PDCA will be implemented to help companies in planning their own supply chain impact and in implementing change.

5.1: Plan, Do, Check, Act

In the 1950's, Edward Deming, a business man known as the father of quality, proposed that business processes should be analyzed and measured; this in order to identify sources of variations that cause products to deviate from customer requirements. He recommended that business processes could be a continuous feedback loop, so that managers can identify and change the parts of the process that need improvements. A diagram to illustrate this continuous process (show in the Figure 15) commonly known as the PDCA cycle and is divided in four stages which are; Plan, Do, Check, and Act.

1. PLAN: Design or revise business process components to improve results.
2. DO: Implement the plan and measure its performance
3. CHECK: Assess the measurements and report the results to decision makers
4. ACT: Decide on changes needed to improve the process

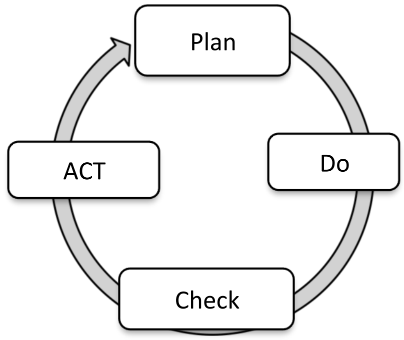

Figure 15: Plan-do-check-Act diagram cycle

This method was selected in order to analyze the supply chain since is relatively easier to understand when compared to others methods and makes constantly improving changes in the supply chain, making it a good option for the industries.

5.2 EVALUATING THE SUPPLY CHAIN WITH THE PDCA

5.2.1:Step 1. -Plan: Set up an objective and plan an environmental management system implementation.

Companies need to recognize that they have to identify, understand and manage issues within their own system before they start working with other industries in their supply chain. This plan needs to be development from the manufacturing process to the possible reuse o disposal of the final product. This can be done; by selecting the potential implementation need it, from the following chart and assess their level of importance of the supply chain in order to start the implementation in the most pollutant area (see Table 1). Note that issues do not need to cause damage the bottom line of a company. Start with those to which is considered an implementation in the company. This table is distributed as the different stages within a supply chain as: Manufacturing, Transportation, Distribution centers and finally the customer final decision of the product that can be disposal or re-use.

Table 1. Supply chain issues and implementations.

SUPPLY CHAIN	ISSUE	IMPLEMENTATION NEED IT
Manufacturing		
Hazardous substances	Product can be of safety, and might be applied in certain countries	
Contamination in water and air	Negative effect on reputation in local community and in the market.	
Waste management	Inefficient use of resources. Investment that is been lost	
Energy used	Inefficient operations, poor productivity and a high cost on energy	
Transportation		
Type of fuel used	Negative effect in the emissions to the different routes used, and effect on reputation	
Routes	Waste on time and repetitive emissions to air.	
Packaging		
Waste	Inefficient used or resources, resulting in a negative cost.	
Inventory levels	Negative impact on cost and effect on delivery method.	
Delivery method	Service delay; inefficient operations causing effects in emissions for the environment.	
Distribution center		
Inefficient operations	Economic viability of product and services.	
Consumer recycle or disposal;		
End of life of product; collection and disposal	Raw may be more expensive than to buy or used reuse material.	

Once that issues are established, it is easier to see what is going to be the principal objective, and establish new objectives and process necessary to deliver expected results of this new goal that is being set up. For example, if the company finds that you are wasting much fuel in the delivered options, establish a goal to fix the company distribution is using, make it efficient as well eco-friendly. Another example is that many industries realize that their company is wasting a lot of material in the process, this result in loss economically and in material utilization. It is important to mention that companies that can deliver products and services with fewer environmental impacts have a significant competitive advantage.

5.2.2:Step 2. -Do: Implement the new process in the supply chain

Once that is identified what the supply chain risk are and the new objectives and process necessary are set up. However, this is often very difficult step for companies with particularly complex supply chains. Many may find that making a change can be expensive and time consuming. But in the end, this could result in a bigger benefit for an industry rather than a waste. For example if the companies realize that in the manufacturing stage a lot of material is wasted, they can determine if this material could be sold to another companies or recycled this in order to recover their money loss. Another important part of this step is that learning to see and

eliminate hidden environmental wastes during implementation can lead to more efficient production by improving the time, quality, and cost results. Coordination of the supply chain and environmental management can facilitate more process in the supply chain improvement and make it easier to apply such as the need to obtain permits, or by identifying environmentally friendly process alternatives. This can result in a significant advantage by providing customers with products and services with less environmental impacts.

5.2.3:Step 3. - Check: Measure the new processes and evaluate environmental performance

Once the new process is applied, make an analysis to measure the efficiency of the new processes is working. Depending in the success in the result that you already set up, at the beginning in the step no.1, you may decide to repeat the step 1 and 2, incorporating your new additional improvements. Once the analysis is done is important to look in the records, and other sources that can provide information on materials usage, and the point to the activities that generate waste or have a significant effect in the environmental. Once you are finally satisfied with the results, you can move on to the final phase.

5.2.4:Step 4.- Act: Analyze the differences

Finally, this last step analyzes the differences to determine their cause. However the use of the PDCA Cycle doesn't necessarily stop there. If you are using the PDCA as continuous improvement initiative, the companies need to loop back to the Plan Phase (Step 1), and seek out further areas for improvement.

Chapter 6: Implementing a new framework in a sustainable supply chain

6.1: Literature review

The literature about sustainable frameworks is very limited and usually does not explain, from an optimal point of view. One of the limitations found the difficult reading for the users, especially when they do not count with the background knowledge. Another problem found in different papers is that many are specific and are difficult to apply in different industries, for example of the paper written by Ezutah, Kuan Yew(2010), where they set up a framework for the automobile industry with specific factors in order to make it more eco-friendly, but are impossible for other types of industries to follow, due to the different factors that are not applicable. Other restriction is that many have different focuses in the process, as Sarkis(1995), who only focuses in the start and end of a product but do not take in consideration what is happening inside of each stage of the supply chain. This makes it difficult for the reader to understand in which stage the problem is happening or in which stage more pollutants are being produced. Among the papers that are easier to be followed, few where identified to be related with a sustainable proposed framework. Sarkis (sarkis, 1995) explores the applicability of a dynamic non-linear multi-attribute decision model. The decision framework is modeled and solved using an analytical network process (ANP); which varies from a standard decision hierarchical decision structure. The major disadvantage of the ANP approach is the large amount of decision-making input required, making it difficult even for rather simple networks.

Seuring and Muller (Seuring and Muller, 2008) provide a review of sustainable supply chain management, based on 191 publications, i.e. they offer a conceptual framework to summarize the research in this field comprising three areas ;(1) environmental, (2) social issues, or (3) both dimensions (environmental and social). Both authors are based on these three triggers, and two strategies are identified. The first one labeled as ‘‘supplier management for risks and performance’’ and the second as “supply chain management for sustainable products”.

Finally this paper proposes a new sustainable framework to the supply chain this in order to fix some problems previously mentioned in different literature reviews. Following the four

steps of the method PDCA as a guideline in order to obtain a more sustainable supply chain. This framework intents to analyze a supply chain not only from beginning to end but also explain in detail each stage that the supply chain follows and applying the steps in a simple way that can be easily followed by different industries.

6.2: AIMS FOR STUDY

Since the beginning of these thesis, it has been exposed how the society has change to a more environmental perspective due to change in the planet cause by the global warming. Companies had been following a set of standards in order to reduce the emissions produce by industries. The presented PDCA framework would help to identify the source of the emission, identify it and solve it. But, in order to prove that this framework is going to have an effect in the supply chain it need to be tested to prove the efficiency. The problem to be solve by using the PDCA framework it was presented by chabane (2010) .The aim of the study used evaluate two main factors;(1) the cost of implementing a supply chain and (2) the emission generated to the environment (Figure 16). Using this problem the goal is to reduce the emissions focus on the part of the stage, by identify the source using the PDCA framework. Make the change that is optional but always taking in consideration the cost of the new change that is being applied. This problem presented will start with the elements of bauxite and carbon anode that are going to be supplier by four suppliers then transported to two plants processed into aluminum and finally transported to distribution centers. Also it is included the installation cost of plants, suppliers and distribution centers. For this problem it would be taken in consideration the boundaries “cradle-to-grave”. (Table 2) summarizes the system boundaries with regard to the general processes/quantities that are considered in the study.

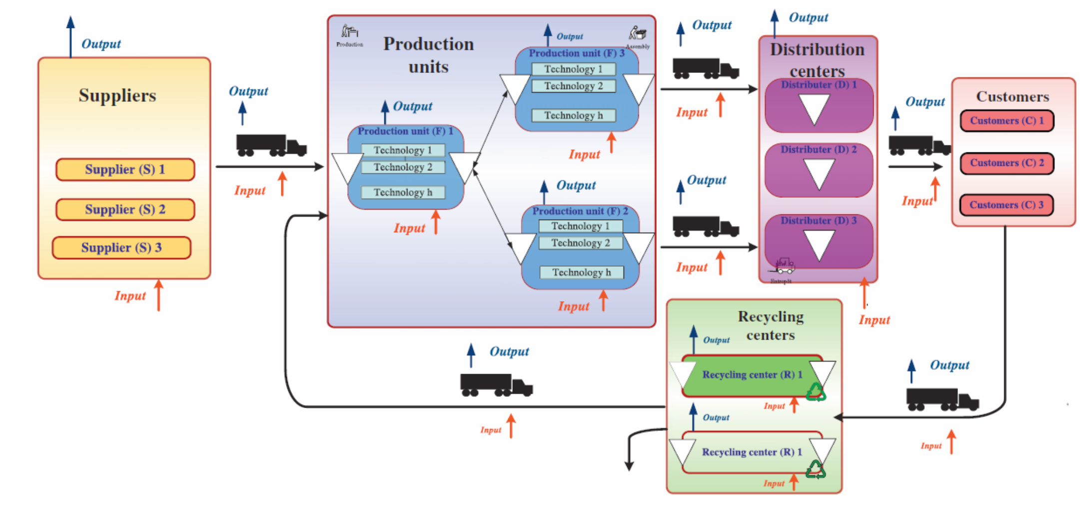

Figure 16: Supply chain network structure.Source: A. Chaabane,2009

Table 2: System boundaries

Included	Excluded
Production units Inputs and output Transportation internal from suppliers to distribution Suppliers(beauxite and carbon anode)	Raw materials Product recycling Use of product Human labor Product disposal Product recycling

6.3 Methodology

The measuring of the emissions becomes an important step that may achieve by the used of PDCA framework, Gabi data and Lingo 13.0. As previously stated, not only is important that the companies become more green but that they standardize this activities in order to improve continuously. Thus, it is important to apply a framework that could help the industries to set rules that could help to diminish emissions that be apply a long the entire supply chain of the

aluminum process. As explain before the LCA is important to establish the critical inputs and outputs at each node of the network over its entire life cycle. This problem would not be only solve the cost of installation but the cost to make the changes in terms of emissions to air.

6.4 Assumptions

The problem to solve, is the production of aluminum bars, it is assumed that each supplier is going to supplier the beauxide and the carbon anode individually to each plant. The extraction of these materials would not be taken in consideration. The transportation among the entire supply chain would be starting from suppliers to the distribution center; the type of fuel used would be diesel, each truck will have same capacity; the cost for transportation of the product will be fixed for the amount of material transported. Once the material is in manufacturing/production it would be transformed into aluminum by the technologies units this would be three for each production process also three these are in series. Finally the aluminum bars would be sent to the distribution centers. (Figure 17) shows the structure of the global supply chain.

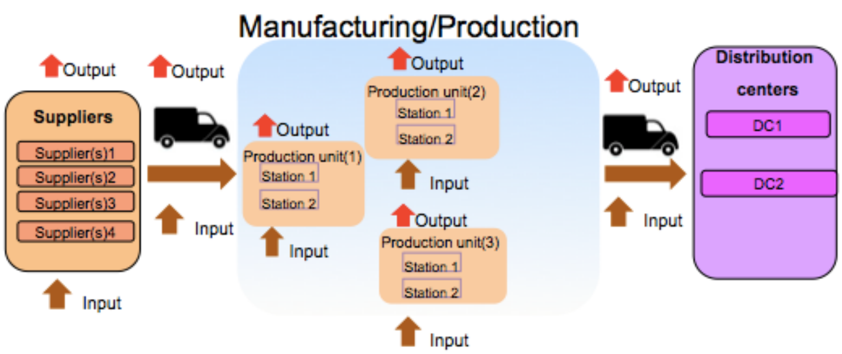

Figure 17: Structure of the global supply chain.

For the first objective that is the cost it would be include the installation of suppliers and distributions center this sites are located in different zones **Z**. A set of potential suppliers **S** can

supply raw materials **R** to a set of sub-contractors and plants **F**. The aluminum is going to be distributed through a set of potential distribution centers **D.**

Let **N** denotes the set of the different nodes of the supply chain network. At each production center, a set of potential technologies **H** is available for use. Each of these technologies needs some inputs (energy, liquid, solid, gazes, etc.) **I**, in addition to materials and generate different outputs (liquid, solid, gazes) **for** transportation **M** are used for the shipment of products between nodes (suppliers, production units, distribution centers, and recycling units). Each transportation mode needs some inputs (e.g. energy and gazes) and may generate some wastes (output).

Before the description of the detailed model, some basic elements about modeling techniques are explained. The production is based on a bill of material that indicates the quantity of raw material or components required to manufacture components or final products. The potential technologies available differ in terms of acquisition and operation costs as well as inputs consumption and output emissions.

6.5 DECISION VARIABLES

To achieve the objective of sustainability and understand the impact of different control parameters on the decision process,several decisions touching various aspects of the supply chain must be taken into account. They are:

a)Decisions related to sites plants and distribution center location:

Y_{FZ}^{L} Binary variable takes a value of 1 if a plant is located at zone zAZ, 0 otherwise.

b) Decisions related to production units:

Q_{MP}^{F}Quantity of product by suppliers MP in production unit F.

Q_{HZ}^{P}Quantity of product PF manufacured using technology H in zone Z.

y_{rs}^{s} Binary variable takes a value of 1 if supplier S is selected for supplying raw material MP during time ,0 otherwise.

y_{F}^{H} Binary variable takes a value of 1 if technology H is selected in production unit F.

y_{pfhf}^{P}Binary variable takes a value of 1 if product PF is manufactured/assembled using technology H at plant F , 0 otherwise.

c) Decisions related to distribution centers

I_{PF}^{d}The inventory level of product PF at distribution center D.

d) Decisions related to transportation

F_{MPPFNM}Quantity of product starting from suppliers MP then to manufacturingPF processed from node to node N using transportation mode M.

e) Decisions related with suppliers

$F_{pnn'mt}$Quantity of product starting from suppliers MP then to manufacturingPF processed from node to node N using transportation mode M.

b) Decisions related to cost of production units:

a_{fdz}^{l} Cost of place distribution center and plants in zone z.

a_{rs}^{s} Cost of select a supplier S and a raw material R.

C_{rsf}^{af} Cost of product by suppliers S to plants F.

a_{hfpr}^{h}Cost of operating production units.

a_{pfhf}^{p} Cost of cost for technology acquisition.

C_{pfhf}^{p}Cost for production line configuration.

6.5 MODEL FORMULATION

This section describes the linear programming model that considers the critical aspects for the design and strategic planning of sustainable supply chains. The choice of multi-objective linear programming (MOLP) as a methodology to investigate this problem is basically because it

helps to find the different strategic decisions (explained in the previous framework: see Fig. 1) of linear objective functions and a single decision maker or a decision making body that guarantee a trade-off with respect to some linear constrains.

6.5.1. Economic objective (F1)

The strategic sustainable supply chain network design described before has the objective to find a trade-off solution between the economic and the environmental performance under the different regulations that GHG emissions and impose constraints related producer responsibility at the end of the production life cycle. The economic objective is evaluated by the total logistic cost. The environmental performance is evaluated by the total emissions of GHG.

The economic dimension includes different costs;

- Location cost (denoted ZC): which are the costs to locate production, distribution, and recycling centers at the different regions.

$$\sum_{F}\sum_{D}\sum_{z} a^{l}_{FDz}\, y^{l}_{FDz}$$

in order to apply these formulation to lindo is important to undestand what are these values going to be translated into lindo.where x_{ijk} would be define as i as the plant(2 plants), j distribution center (2), k zone(3).the next table (Table 3) would represent the location cost and the cost implied.

Table 3. Location cost table.

location zone cost						
plant	DC1			DC2		
p1	z1	z2	z3	z1	z2	z3
	X111	x112	x113	x121	x122	x123
cost	1200	2500	3201	3600	4500	2400
p1	x211	x212	x213	x221	x222	x223
cost	1256	2523	3010	4569	2564	2340

In these table the cost has been assing randomly and the pink part is the one that is going be binary also randomly. This is going to be subjected to minimization of cost.

Min

1200x111+3201x113+2500x112+3600x121+4500x122+2400x123+1256x211+2523x212+3010x213+4569x221+2564x222

subjected to

x111+x211+x121+x221	>=	1	constrains of zone 1
x112+x212+x121+x221	>=	1	constrains of zone 2
x113+x213+x123+x223	>=	1	constrains of zone 3
x111+x211	>=	1	constrains of dc per zone
x112+x212	>=	1	constrains of dc per zone
x121+x221	>=	1	constrains of dc per zone
x122+x222	>=	1	constrains of dc per zon

In these formulation is visible to see the constrains ,that requires that at least one plant be present in the zone. As well as un distribution center per zone. Once this is finish it will be add to all the summatory of element that are SC+TC+PC+DC.

• Supply costs (denoted SC): which are the costs to acquire materials

Fixed cost to establish contracts with suppliers

$$\sum_{Mp}\sum_{S} a^{s}_{MpST} y^{s}_{pnt}$$ *Fixed cost contracts*

$$\sum_{Mp}\sum_{S}\sum_{F} c^{af}_{MpST} f_{pnn'mt}$$ *Variable cost for raw materials acquisition*

in order to apply these formulation is important to undestand what are these values going to be translated into lindo.first is important to know the fixed cost with contracts.where y_{ij} would be define as i as the raw materials(anode,beauxide), j supplier (2).The next table (Table 4) would represent the Fixed cost implied.

Table 4 Fixed cost contracts.

	s1	s2	s3	s4
r1	y11	y12	y13	y14
cost	236	214	258	369
r2	y21	y22	y23	y24
cost	325	125	236	214

In these table the cost has been assing randomly and the pink part is the one that is going be binary and the cost was implemented randomly. This is going to be subjected to minimization of cost; in these formulation is visible to see the constrains, the first one stablish that each supplier capacity the second requires to buy at least one product form each supplier. The last one requires to take in consideration at leas one supplier,the last constrain is the capacity of the plant.

Second, is important to know the ***variable cost for raw materials acquisition***.where z_{ijk} would be define as i as the raw materials(anode,beauxide), j supplier (2), k plant(3). The next table (Table 5) would represent the variable cost for raw materials adquisition.

Table 5. Variable cost for material acquisition

	s1		s2		s3		s4	
	p1	p2	p1	p2	p1	p2	p1	p2
r1	z111	z112	z121	z122	z131	z132	z141	z142
cost	200	250	100	200	410	360	457	468
r2	z211	z212	z221	z222	z231	z232	z241	z242
cost	100	200	200	250	698	454	651	356

In these table the cost has been assing randomly the pink part is the one that is going be the amount of the cost that is going to be for each raw material,from the type of suplier in each plant. This is going to be subjected to minimization of cost; in these formulation is visible to see the constrains, stablish that each supplier is going to at least must plan storage space for at least 11000 tons for supplier1 for supplier 2 and supplier 3 at least 13000, at last 18000 from supplier. Another constrain taking in consideration is the capacity of plan that is lest than 60,000.

- Production costs (denoted PC): which are the costs to manufacture products.
    (1) Fixed cost for technology acquisition (3) Fixed cost for production line configuration, (4) Variable cost for manufacturing.

$$\sum_{H}\sum_{F}\sum_{pr} a^{h}_{HFpr} Y^{h}_{HFpr} \qquad (1)$$

$$\sum_{R}\sum_{H}\sum_{F} a^{p}_{PFHF} y^{p}_{PFHF} \qquad (2)$$

$$\sum_{R}\sum_{H}\sum_{F} c^{p}_{PFHF} Q^{P}_{PFHF} \qquad (3)$$

Starting with the formula of ***Fixed cost for technology acquisition***. The variables are w_{ijk} this would be define as i as technology(3), j plant(2), k process(3). the next table (Table 6) would represent the Fixed cost for technology acquisition.

Table 6. Fixed cost for technology acquisition.

	plant1			plant2		
	p1	p2	p3	p1	p2	p3
h 1	w111	w112	w113	w121	w122	w123
Cost	562	536	524	562	536	546
h2	w211	w212	w213	w221	w222	w223
cost	316	304	324	316	304	354
h3	w311	w312	w313	w321	w322	w323
cost	136	132	134	136	132	132

Also, in these formulation is a binary variable takes value if technology is selected or not. The cost is randomly createrd for the cost of acquisition of technology in each plant and process. The constrains, this establishes a technology per plant, also that each technology has the capacity of produce no more than than 2000,25000,18000 per technology.

The second formulation is the ***Fixed cost for production line configuration***, where v_{ijk} would be define as i as beauxide,anode(2), j technology(3),k plant(2). The main equation is the cost for the production of one unit. The next table (Table 7) would represent the Fixed cost for production line configuration.

Table 7.Fixed cost for production line configuration.

	tech1		tech2		tech3	
raw	plant1	plant2	plant1	plant2	plant1	plant2
1	v111		v121	v122	v131	v132
	0	1	0	1		
	12	12	16	16	17	17
2	v211	v212	v221	v222	v231	v232
	12	12	16	16	17	17

Is visible to see that in each constrains at least one product is going to be selected, each technology have a limit that can be produce this is also establish with the constraint. As being part of binary function is selected with technology in a plant. This is the cost that each technology is going to charge per production of 1 ton of aluminum. Constrains, of this process is that each technology have a capacity of production of tons of lest than 4000 per technology either using raw material 1 or raw material 2.

The third formulation the ***Variable cost for manufacturing***. where k_{ijk} would be define as i as beauxide,anode(2), j technology(3),plant(2). the next table (Table 8) would represent the variable cost for manufacturing.

Table 8. Variable cost for manufacturing.

	tech1		tech2		tech3	
	plant1	plant2	plant1	plant2	plant1	plant2
raw						
1	k111	k112	k121	k122	w131	w132
	2323					
cost	125	326	231	201	197	326
2	k211	k212	k221	k222	w231	w232
	234	453	345	201	147	326

Variable cost is how much is going to cost the manufacture of the aluminum using the two main materials that are taken in consideration to the demand of the manufacture products. The pink area is the quantity that is going to be the amount produce. One constrain in this part is that raw

material 1 and material 2 are going to be generated in the same quantity because these are transformed into aluminum.

The fifth formulation is the ***Transportation cost*** (denoted TC): which are the costs to move products.

Minimize $\sum_i \sum_j c_{ij}x_{ij}$

The price from each supplier to plants (Table 9). The cost will be fix to all the types of transportation and this will not take in consideration neither distances or number or trucks used.

Table 9. Table of trucks cost from supppliers to plants

Logging site	*Plant1*	*Plant 2*
Supplier 1	$120	$60
Supplier 2	$100	$68
Supplier 3	$184	$104
Supplier 4	$200	$48
Supplier 5	$120	$92

Another part of the formulation of transportation is the ***Transportation cost from plants to distribution centers*** (denoted TC): which are the costs to move products.

Minimize $\sum_i \sum_j c_{ij}x_{ij}$

The distance from each supplier to plants is in (Table 10). The cost will be fix to all the types of transportation and this will not take in consideration neither distances or number or trucks used.

Table 10. Truck cost from plants to distribution centers.

Logging site	*Plant1*	*Plant 2*
Plant 1	$200	$60
Plant 2	$100	$68

6.5.2. Environmental objective (F2)

LCA based cost (denoted LC): We are considering that the company will identify some strategic input costs (water, oil, energy, etc.) in the economic objective function. Also, some outputs (waste, co-products, etc.) need further treatment and there are also some related costs.

- The consumption of the input during the entire supply chain:

$$(\sum_R\sum_H\sum_F EF^{S}_{rhf} Q^{s}_{RHF}) + (\sum_R\sum_H\sum_F\sum_{pr} EF^{P}_{RHFpr} Q^{P}_{RHFpr}) + (\sum_F\sum_D EF^{D}_{FRD} Q^{D}_{FRD}) + (\sum_S\sum_F EF^{T}_{FRD}) + (\sum_F\sum_d EF^{T}_{FD})$$

6.5.2.2 Emissions output

- The emissions of output during the Supplier process.

$$(\sum_R\sum_H\sum_F EF^{S}_{rhf} Q^{s}_{RHF})$$

Variable cost for manufacturing, where w_{ijkz} would be define as i as the raw material, beauxide and carbone anode(2), j technology used(3),k the plants(2),z zones(3).in the following table,(Table 11) the emissions are show of the emissions generated by the different raw materials in the different suppliers.

Table 11. Emissions of output during the supplier procees

	supplier 1		supplier 2		supplier 3		supplier 4	
	planta 1	planta 2	planta 1	planta 2	planta 1	planta 2	plant 1	plant 2
1	z111	z112	z121	z122	z131	z132	z141	z142
	0.000691	0.0071	0.00879	0.00979	0.000791	0.000791	0.000979	0.000969
2	z211	z212	z221	z222	z231	z232	z241	z242
	0.000591	0.000491	0.000579	0.000879	0.00691	0.000791	0.000879	0.000679

- The emissions of output during the production process.

$$(\sum_R\sum_H\sum_F\sum_{pr} EF^{P}_{RHFpr} Q^{P}_{RHFpr})$$

In these formulation the emissions are going to be multiply be the amount that is being produce, where w_{ijkz} would be define as i as process the beauxide and carbone anode(2), j technology(3),k plants(2),z zones(3). in the following table (Table 12) the structure of the

emissions are show. This table would show how much emission are generated by using the type of technology, in different plants in order to process aluminum bars.

Table 12 .The emissions of output during the production process

	tech1						tech2						tech3					
	plant1			plant2			plant1			plant2			plant1			plant2		
raw	p1	p2	p3	p1	p2	p3	p1	p2	p3	p1	p2	p3	p1	p2	p3	p1	p2	p3
1	w1111	w1112	w1113	w1121	w1122	w1123	w1211	w1212	w1213	w1221	w1222	w1223	w1311	w1312	w1313	w1321	w1322	w1323
emission	0.00079	0.00079	0.00079	0.00069	0.0069	0.00069	0.00077	0.00077	0.00077	0.00059	0.00059	0.00059	0.079	0.079	0.079	0.0007	0.0007	0.0007
2	w2111	w2112	w2113	w2121	w2122	w2123	w2211	w2212	w2213	w2221	w2222	w2223	w2311	w2312	w2312	w2321	w2322	w2323
	0.0388	0.0388	0.0388	0.0376	0.0376	0.0376	0.039	0.039	0.039	0.0398	0.0398	0.0398	0.029	0.029	0.029	0.0288	0.0288	0.0288

- The emissions of output during the Distribution process.

$$(\sum_{F}\sum_{D} EF^{D}_{FRD} Q^{D}_{FRD})$$

The variables. For the formulation of emissions during the Distribution process, where y_{ijkz} would be define as i as process the beauxide and carbone anode(2), j technology(3),k plants(2),z zones(3). These are the emissions of the product in the period of time that the product is storage. For the purpose of emissions the electricity was taken in consideration as major input (Table 13).

Table 13. Emission during the Distribution center

	dc1	dc2
	aluminio	aluminio
1	y1111	y1211
	0.00656	0.00456
2	y2111	y2211
	0.000576	0.00726

- The emissions of the output during the Transportation process.

It is important to understand what are going to be the emission of the transportation used, in this case these are the emission in the air from the transportation from each supplier to each plant. These emissions are in the following (Table 14).

Table 14. Emission from suppliers to plants

	planta 1 t1	planta 2 t2
Supplier 1	0.039	0.00489
Supplier 2	0.049	0.0039
Supplier3	0.0056	0.00389
Supplier 4	0.0039	0.0039
Supplier 5	0.0049	0.039

As well to know the emission to the air in the transportation from each plant to the different distribution centers. These emissions are in the following table (Table 15)

Table 15 Emissions from plants to Distribution center

Logging site	*dc*	*dc*
Plant 1	0.0519	0.0289
Plant 2	0.0249	0.0049

All the transportation has been applied to the same capability and distance (not inclination or surface of highways would be taken in consideration). All the trucks will be with different model, according with GaBi but all will be taking in considerations that are fuel by diesel.

6.5 DATA COLLECTION

The primary goal in this paper is to demonstrate how the PDCA framework can be used in order to evaluate the impact of different legislations on the supply chain strategy and planning.

In practice, the model could be modified to capture some specific strategic considerations of a given supply chain and populated with additional data.

For the aim of the study, some parameters are estimated; the others ones are collected from the available information on the web. For example, the model developed in this paper highlights the importance of LCA data in order to help and inform managerial decision-making. Numeric estimates of air emissions, solid waste generation, material consumption, are valuable in estimating model's parameters, thus enabling the bridging of operational and environmental decisions. All the inputs and output were obtain from GaBi - the world's premium Life Cycle Assessment Software. This is the Powerful LCA Tools and LCA Databases for Product and Process Sustainability Analyses. An important factor is that Gabi is able to help us with the type of transportation as show in the following (Figure 18). One of the biggest help is that previously explain in an LCA is important to transform the gases into terms of CO2. This program help to minimize the time of calculation providing the exact amount of Carbon dioxide equivalent (CO2,eq).

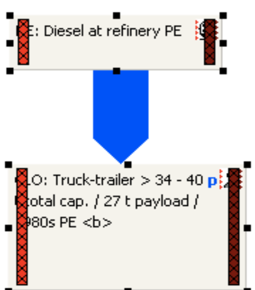

Figure 18. GaBi software, fuel and type of transportation

GaBi software give the result of 0.003191kgCO_2e as result that for each 50 m that this truck drives using this type of fuel would provide to us that is the emission to environment that is going to be produce. As previously show the amount of C02e in each stage of transportation was obtain by the library of GaBi.

6.6 SOLUTION METHOD

Different commercially available optimization software exists today to solve MIP optimization problems. As discussed in previous section, it is currently impossible to use real data to populate the model. But, previous to understand what software was used to solved the problem. However, to demonstrate the practical solvability of the model, we randomly generate some numerical scenarios of parameters and constraints, and solve the model using the LINGO version of LINDO systems Inc. on PC running Windows XP. The mean and median run times per numerical scenario with the default LINGO solver settings were 700 and 600 s, respectively, which is a very practical amount of time. Although this example is with limited number of products and sites (suppliers, production units, and distribution centers), more sophisticated global optimization approaches for large-scale optimization problem could be used to solve large-scale supply chain network.

6.7 MODEL FORMULATION

Once that it is divided each one of the process and explained, it is important to put them in a equation that be able to obtain the two main functions that we are looking for this are: minimization of cost and emissions.

For the formulation of cost the following is the formulation;

$$Min\ ZC + SC + y_{11}\left[Z\ cost\left[t_{1(plant)1(DC)}\left(Z_{1(raw\ )11(tech)1(pr)} \times cost\ w \times cost\ v \times cost\ k \times binW_{111}(cost\ T_{supplier\ \ to\ pl} \ + cost\ T_{\ pl\ to\ Dc}\right)\right]\right]$$

The product is being analyzed since the supplier until the distribution center. Taking in consideration all the cost from transportation, starting from the suppliers to plants and from plants to distribution centers. Also, taking in consideration introduction of technologies, and how much that technology is going to cost individually and by tons. The following equation explains how these values were distributed in a more detail explanation by only using the supplier 1, plant 1, and distribution centers one and two (Figure 19,Figure 20).

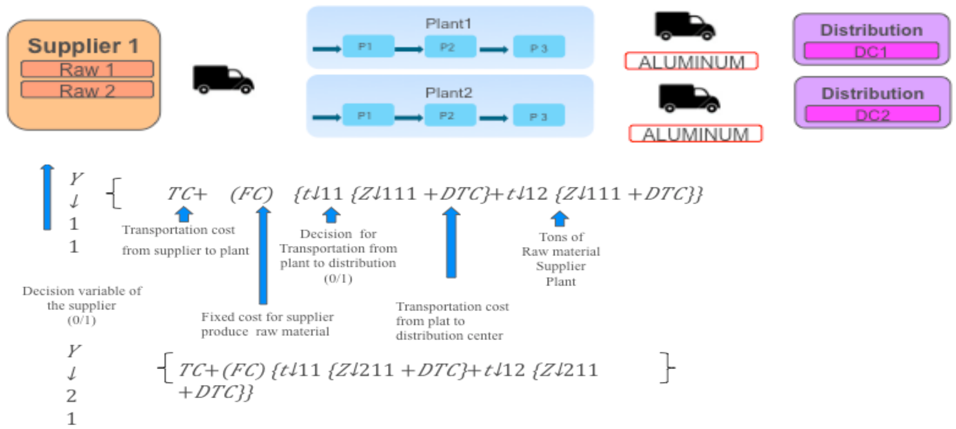

Figure 19: Equation of main operation

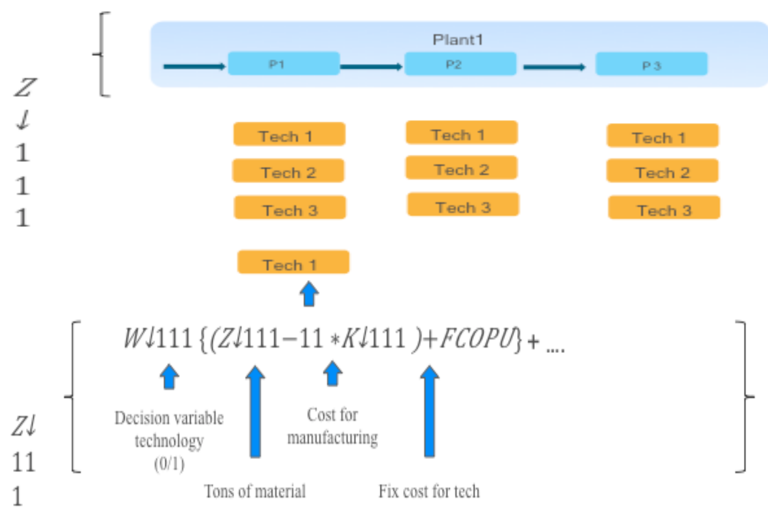

Figure 20: Equation inside the process.

As is visible in the figure 19, the raw materials are processed form the suppliers, passing the production center and finally the distribution center. In the figure 20 the production center is explain in a more detail way of how the product pass though each of the process in series and using the three different technologies.

The following equation is the main equation of using the four suppliers, the two plants and the distribution centers. This was input was enter into lingo.

$$
\begin{aligned}
min\ 120x_{111} + \ 2500x_{112} + \ 3201x_{113} + 3600x_{121} + 4500x_{122} + \ 2400x_{123} + 1256x_{211} \\
+ 2523x_{212} + \ 3010x_{213} + 4549x_{221} + 2564x_{222} + \ 2340x_{223} + 236y_{11} \\
+ 214y_{12} + 258y_{13} + 369y_{14} + 325y_{21} + 125y_{22} + 236y_{23} + 214y_{24} \\
+ y_{11}\big[200[t_{11}(Z_{111-11} * 562 * 12 * 125 * W_{111} + Z_{111-21} * 316 * 16 * 231 \\
* W_{211} + Z_{111-31} * 136 * 17 * 197 * W_{311} + Z_{111-12} * 536 * 12 * 234 * W_{112} \\
+ Z_{111-22} * 304 * 16 * 145 * W_{212} + Z_{111-32} * 132 * 17 * 147 * W_{312} + Z_{111-13} \\
* 524 * 12 * 125 * W_{113} + Z_{111-23} * 324 * 16 * 231 * W_{213} + Z_{111-33} * 134 \\
* 17 * 197W_{313} + 120 + \ 200)]\big] \\
+ y_{11}\big[200[t_{12}(Z_{111-11} * 562 * 12 * 125 * W_{111} + Z_{111-21} * 316 * 16 * 231 \\
* W_{211} + Z_{111-31} * 136 * 17 * 197 * W_{311} + Z_{111-12} * 536 * 12 * 234 * W_{112} \\
+ Z_{111-22} * 304 * 16 * 145 * W_{212} + Z_{111-32} * 132 * 17 * 147 * W_{312} + Z_{111-13} \\
* 524 * 12 * 125 * W_{113} + Z_{111-23} * 324 * 16 * 231 * W_{213} + Z_{111-33} * 134 \\
* 17 * 197W_{313} + 120 + \ 200)]\big] \\
+ y_{11}\big[250[t_{21}(Z_{112-11} * 562 * 12 * 326 * W_{121} + Z_{112-21} * 316 * 16 * 201 \\
* W_{221} + Z_{112-31} * 136 * 17 * 326 * W_{321} + Z_{112-12} * 536 * 12 * 326 * W_{122} \\
+ Z_{112-22} * 304 * 16 * 201 * W_{222} + Z_{112-32} * 132 * 17 * 326 * W_{312} + Z_{112-13} \\
* 524 * 12 * 326 * W_{123} + Z_{112-23} * 324 * 16 * 201 * W_{223} + Z_{111-33} * 134 \\
* 17 * 326W_{313} + 60 + \ 100)]\big]
\end{aligned}
$$

$+y_{11}\big[250[t_{22}(Z_{112-11} * 562 * 12 * 326 * W_{121} + Z_{112-21} * 316 * 16 * 201 * W_{221} + Z_{112-31} * 136 * 17 * 326 * W_{321} + Z_{112-12} * 536 * 12 * 326 * W_{122} + Z_{112-22} * 304 * 16 * 201 * W_{222} + Z_{112-32} * 132 * 17 * 326 * W_{312} + Z_{112-13} * 524 * 12 * 326 * W_{123} + Z_{112-23} * 324 * 16 * 201 * W_{223} + Z_{111-33} * 134 * 17 * 326 W_{313} + 60 + 68)]\big]$t into the lingo program.

$$+y_{12}\big[200[t_{21}(Z_{122-11} * 562 * 12 * 326 * W_{121} + Z_{112-21} * 316 * 16 * 201 * W_{221} + Z_{122-31} * 136 * 17 * 326 * W_{321} + Z_{122-12} * 536 * 12 * 326 * W_{122} + Z_{122-22} * 304 * 16 * 201 * W_{222} + Z_{122-32} * 132 * 17 * 326 * W_{312} + Z_{122-13} * 524 * 12 * 326 * W_{123} + Z_{122-23} * 324 * 16 * 201 * W_{223} + Z_{121-33} * 134 * 17 * 326 W_{313} + 68 + 100)]\big]$$

$$+ y_{12}\big[200[t_{22}(Z_{122-11} * 562 * 12 * 326 * W_{121} + Z_{112-21} * 316 * 16 * 201 * W_{221} + Z_{122-31} * 136 * 17 * 326 * W_{321} + Z_{122-12} * 536 * 12 * 326 * W_{122} + Z_{122-22} * 304 * 16 * 201 * W_{222} + Z_{122-32} * 132 * 17 * 326 * W_{312} + Z_{122-13} * 524 * 12 * 326 * W_{123} + Z_{122-23} * 324 * 16 * 201 * W_{223} + Z_{121-33} * 134 * 17 * 326 W_{313} + 68 + 68)]\big]$$

$$+y_{12}\big[100[t_{11}(Z_{121-11} * 562 * 12 * 125 * W_{111} + Z_{121-21} * 316 * 16 * 231 * W_{211} + Z_{121-31} * 136 * 17 * 197 * W_{311} + Z_{121-12} * 536 * 12 * 125 * W_{112} + Z_{121-22} * 304 * 16 * 231 * W_{212} + Z_{121-32} * 132 * 17 * 197 * W_{312} + Z_{121-13} * 524 * 12 * 125 * W_{113} + Z_{121-23} * 324 * 16 * 231 * W_{213} + Z_{121-33} * 134 * 17 * 197 W_{313} + 100 + 200)]\big]$$

$$+ y_{12}\big[100[t_{12}(Z_{121-11} * 562 * 12 * 125 * W_{111} + Z_{121-21} * 316 * 16 * 231 * W_{211} + Z_{121-31} * 136 * 17 * 197 * W_{311} + Z_{121-12} * 536 * 12 * 125 * W_{112} + Z_{121-22} * 304 * 16 * 231 * W_{212} + Z_{121-32} * 132 * 17 * 197 * W_{312} + Z_{121-13} * 524 * 12 * 125 * W_{113} + Z_{121-23} * 324 * 16 * 231 * W_{213} + Z_{121-33} * 134 * 17 * 197 W_{313} + 100 + 60)]\big]$$

$$+y_{13}\Big[410[t_{11}(Z_{131-11} * 562 * 12 * 125 * W_{111} + Z_{131-21} * 316 * 16 * 231 * W_{211} + Z_{131-31} * 136 * 17 * 197 * W_{311} + Z_{131-12} * 536 * 12 * 125 * W_{112} + Z_{131-22} * 304 * 16 * 231 * W_{212} + Z_{131-32} * 132 * 17 * 197 * W_{312} + Z_{131-13} * 524 * 12 * 125 * W_{113} + Z_{131-23} * 324 * 16 * 231 * W_{213} + Z_{131-33} * 134 * 17 * 197 W_{313} + 184 + 200)]\Big]$$

$$+ y_{13}\Big[410[t_{12}(Z_{131-11} * 562 * 12 * 125 * W_{111} + Z_{131-21} * 316 * 16 * 231 * W_{211} + Z_{131-31} * 136 * 17 * 197 * W_{311} + Z_{131-12} * 536 * 12 * 125 * W_{112} + Z_{131-22} * 304 * 16 * 231 * W_{212} + Z_{131-32} * 132 * 17 * 197 * W_{312} + Z_{131-13} * 524 * 12 * 125 * W_{113} + Z_{131-23} * 324 * 16 * 231 * W_{213} + Z_{131-33} * 134 * 17 * 197 W_{313} + 184 + 60)]\Big]$$

$$+y_{13}\Big[360[t_{21}(Z_{132-11} * 562 * 12 * 326 * W_{121} + Z_{132-21} * 316 * 16 * 201 * W_{221} + Z_{132-31} * 136 * 17 * 326 * W_{321} + Z_{132-12} * 536 * 12 * 326 * W_{122} + Z_{132-22} * 304 * 16 * 201 * W_{222} + Z_{132-32} * 132 * 17 * 326 * W_{322} + Z_{132-13} * 524 * 12 * 326 * W_{123} + Z_{132-23} * 324 * 16 * 201 * W_{223} + Z_{131-33} * 134 * 17 * 326 W_{323} + 104 + 100)]\Big]$$

$$+ y_{13}\Big[360[t_{21}(Z_{132-11} * 562 * 12 * 326 * W_{121} + Z_{132-21} * 316 * 16 * 201 * W_{221} + Z_{132-31} * 136 * 17 * 326 * W_{321} + Z_{132-12} * 536 * 12 * 326 * W_{122} + Z_{132-22} * 304 * 16 * 201 * W_{222} + Z_{132-32} * 132 * 17 * 326 * W_{322} + Z_{132-13} * 524 * 12 * 326 * W_{123} + Z_{132-23} * 324 * 16 * 201 * W_{223} + Z_{131-33} * 134 * 17 * 326 W_{323} + 104 + 68)]\Big]$$

$$+y_{14}\Big[457[t_{11}(Z_{141-11}*562*12*125*W_{111}+Z_{141-21}*316*16*231*W_{211}+Z_{141-31}$$
$$*136*17*197*W_{311}+Z_{141-12}*536*12*125*W_{112}+Z_{141-22}*304$$
$$*16*231*W_{212}+Z_{141-32}*132*17*197*W_{312}+Z_{141-13}*524*12$$
$$*125*W_{113}+Z_{141-23}*324*16*231*W_{213}+Z_{141-33}*134*17$$
$$*197W_{313}+48+\ 200)]\Big]$$
$$+\ y_{14}\Big[457[t_{12}(Z_{141-11}*562*12*125*W_{111}+Z_{141-21}*316*16*231$$
$$*W_{211}+Z_{141-31}*136*17*197*W_{311}+Z_{141-12}*536*12*125*W_{112}$$
$$+Z_{141-22}*304*16*231*W_{212}+Z_{141-32}*132*17*197*W_{312}$$
$$+Z_{141-13}*524*12*125*W_{113}+Z_{141-23}*324*16*231*W_{213}$$
$$+Z_{141-33}*134*17*197W_{313}+48+\ 60)]\Big]$$
$$+y_{14}\Big[468[t_{21}(Z_{142-11}*562*12*326*W_{121}+Z_{142-21}*316*16*201*W_{221}+Z_{142-31}$$
$$*136*17*326*W_{321}+Z_{142-12}*536*12*326*W_{122}+Z_{142-22}*304$$
$$*16*201*W_{222}+Z_{142-32}*132*17*326*W_{322}+Z_{142-13}*524*12$$
$$*326*W_{123}+Z_{142-23}*324*16*201*W_{223}+Z_{142-33}*134*17$$
$$*326W_{323}+48+\ 100)]\Big]$$
$$+\ y_{14}\Big[468[t_{21}(Z_{142-11}*562*12*326*W_{121}+Z_{142-21}*316*16*201$$
$$*W_{221}+Z_{142-31}*136*17*326*W_{321}+Z_{142-12}*536*12*326*W_{122}$$
$$+Z_{142-22}*304*16*201*W_{222}+Z_{142-32}*132*17*326*W_{322}$$
$$+Z_{142-13}*524*12*326*W_{123}+Z_{142-23}*324*16*201*W_{223}$$
$$+Z_{142-33}*134*17*326W_{323}+48+\ 68)]\Big]$$

$$+y_{21}\big[200[t_{21}(Z_{212-11}*562*12*453*W_{121}+Z_{212-21}*316*16*201*W_{221}+Z_{212-31}$$
$$*136*17*326*W_{321}+Z_{212-12}*536*12*453*W_{122}+Z_{212-22}*304$$
$$*16*201*W_{222}+Z_{212-32}*132*17*326*W_{322}+Z_{212-13}*524*12$$
$$*453*W_{123}+Z_{212-23}*324*16*201*W_{223}+Z_{212-33}*134*17$$
$$*326W_{323}+60+\ 100)]\big]$$
$$+y_{21}\big[200[t_{22}(Z_{212-11}*562*12*453*W_{121}+Z_{212-21}*316*16*201$$
$$*W_{221}+Z_{212-31}*136*17*326*W_{321}+Z_{212-12}*536*12*453*W_{122}$$
$$+Z_{212-22}*304*16*201*W_{222}+Z_{212-32}*132*17*326*W_{322}$$
$$+Z_{212-13}*524*12*453*W_{123}+Z_{212-23}*324*16*201*W_{223}$$
$$+Z_{212-33}*134*17*326W_{323}+60+\ 68)]\big]$$
$$+y_{21}\big[102[t_{11}(Z_{211-11}*562*12*234*W_{111}+Z_{211-21}*316*16*345*W_{211}+Z_{211-31}$$
$$*136*17*147*W_{311}+Z_{211-12}*536*12*234*W_{112}+Z_{211-22}*304$$
$$*16*345*W_{212}+Z_{211-32}*132*17*147*W_{312}+Z_{211-13}*524*12$$
$$*234*W_{113}+Z_{211-23}*324*16*345*W_{213}+Z_{211-33}*134*17$$
$$*147W_{313}+120+\ 200)]\big]$$
$$+y_{21}\big[102[t_{11}(Z_{211-11}*562*12*234*W_{111}+Z_{211-21}*316*16*345$$
$$*W_{211}+Z_{211-31}*136*17*147*W_{311}+Z_{211-12}*536*12*234*W_{112}$$
$$+Z_{211-22}*304*16*345*W_{212}+Z_{211-32}*132*17*147*W_{312}$$
$$+Z_{211-13}*524*12*234*W_{113}+Z_{211-23}*324*16*345*W_{213}$$
$$+Z_{211-33}*134*17*147W_{313}+120+\ 200)]\big]$$

$$+y_{22}\Big[200[t_{11}(Z_{221-11}*562*12*234*W_{111}+Z_{221-21}*316*16*345*W_{211}+Z_{221-31}$$
$$*136*17*147*W_{311}+Z_{221-12}*536*12*234*W_{112}+Z_{221-22}*304$$
$$*16*345*W_{212}+Z_{221-32}*132*17*147*W_{312}+Z_{221-13}*524*12$$
$$*234*W_{113}+Z_{221-23}*324*16*345*W_{213}+Z_{221-33}*134*17$$
$$*147W_{313}+100+\ 200)]\Big]$$
$$+\ y_{22}\Big[200[t_{12}(Z_{221-11}*562*12*234*W_{111}+Z_{221-21}*316*16*345$$
$$*W_{211}+Z_{221-31}*136*17*147*W_{311}+Z_{221-12}*536*12*234*W_{112}$$
$$+Z_{221-22}*304*16*345*W_{212}+Z_{221-32}*132*17*147*W_{312}$$
$$+Z_{221-13}*524*12*234*W_{113}+Z_{221-23}*324*16*345*W_{213}$$
$$+Z_{221-33}*134*17*147W_{313}+10+\ 60)]\Big]$$
$$+\ y_{22}\Big[250[t_{21}(Z_{222-11}*562*12*453*W_{121}+Z_{222-21}*316*16*201$$
$$*W_{221}+Z_{222-31}*136*17*326*W_{321}+Z_{222-12}*536*12*453*W_{122}$$
$$+Z_{222-22}*304*16*201*W_{222}+Z_{222-32}*132*17*326*W_{322}$$
$$+Z_{222-13}*524*12*453*W_{123}+Z_{222-23}*324*16*201*W_{223}$$
$$+Z_{222-33}*134*17*326W_{323}+68+\ 100)]\Big]$$
$$+y_{22}\Big[250[t_{22}(Z_{222-11}*562*12*453*W_{121}+Z_{222-21}*316*16*201*W_{221}+Z_{222-31}$$
$$*136*17*326*W_{321}+Z_{222-12}*536*12*453*W_{122}+Z_{222-22}*304$$
$$*16*201*W_{222}+Z_{222-32}*132*17*326*W_{322}+Z_{222-13}*524*12$$
$$*453*W_{123}+Z_{222-23}*324*16*201*W_{223}+Z_{222-33}*134*17$$
$$*326W_{323}+68+\ 68)]\Big]$$

$$+y_{23}\Big[454[t_{21}(Z_{232-11}*562*12*453*W_{121}+Z_{232-21}*316*16*201*W_{221}+Z_{232-31}$$
$$*136*17*326*W_{321}+Z_{232-12}*536*12*453*W_{122}+Z_{232-22}*304$$
$$*16*201*W_{222}+Z_{232-32}*132*17*326*W_{322}+Z_{232-13}*524*12$$
$$*453*W_{123}+Z_{232-23}*324*16*201*W_{223}+Z_{232-33}*134*17$$
$$*326W_{323}+104+\ 100)]\Big]$$
$$+\,y_{23}\Big[454[t_{22}(Z_{232-11}*562*12*453*W_{121}+Z_{232-21}*316*16*201$$
$$*W_{221}+Z_{232-31}*136*17*326*W_{321}+Z_{232-12}*536*12*453*W_{122}$$
$$+Z_{232-22}*304*16*201*W_{222}+Z_{232-32}*132*17*326*W_{322}$$
$$+Z_{232-13}*524*12*453*W_{123}+Z_{232-23}*324*16*201*W_{223}$$
$$+Z_{232-33}*134*17*326W_{323}+104+\ 68)]\Big]$$
$$+y_{23}\Big[698[t_{11}(Z_{231-11}*562*12*234*W_{111}+Z_{231-21}*316*16*345*W_{211}+Z_{231-31}$$
$$*136*17*147*W_{311}+Z_{231-12}*536*12*234*W_{112}+Z_{231-22}*304$$
$$*16*345*W_{212}+Z_{231-32}*132*17*147*W_{312}+Z_{231-13}*524*12$$
$$*234*W_{113}+Z_{231-23}*324*16*345*W_{213}+Z_{231-33}*134*17$$
$$*147W_{313}+184+\ 200)]\Big]$$
$$+\,y_{23}\Big[698[t_{12}(Z_{231-11}*562*12*234*W_{111}+Z_{231-21}*316*16*345$$
$$*W_{211}+Z_{231-31}*136*17*147*W_{311}+Z_{231-12}*536*12*234*W_{112}$$
$$+Z_{231-22}*304*16*345*W_{212}+Z_{231-32}*132*17*147*W_{312}$$
$$+Z_{231-13}*524*12*234*W_{113}+Z_{231-23}*324*16*345*W_{213}$$
$$+Z_{231-33}*134*17*147W_{313}+184+\ 60)]\Big]$$

$$+y_{24}\Big[651[t_{11}(Z_{241-11}*562*12*234*W_{111}+Z_{241-21}*316*16*345*W_{211}+Z_{241-31}*136*17*147*W_{311}+Z_{241-12}*536*12*234*W_{112}+Z_{241-22}*304*16*345*W_{212}+Z_{241-32}*132*17*147*W_{312}+Z_{241-13}*524*12*234*W_{113}+Z_{241-23}*324*16*345*W_{213}+Z_{241-33}*134*17*147W_{313}+200+\ 200)]\Big]$$

$$+y_{24}\Big[651[t_{12}(Z_{241-11}*562*12*234*W_{111}+Z_{241-21}*316*16*345*W_{211}+Z_{241-31}*136*17*147*W_{311}+Z_{241-12}*536*12*234*W_{112}+Z_{241-22}*304*16*345*W_{212}+Z_{241-32}*132*17*147*W_{312}+Z_{241-13}*524*12*234*W_{113}+Z_{241-23}*324*16*345*W_{213}+Z_{241-33}*134*17*147W_{313}+200+\ 60)]\Big]$$

$$+y_{24}\Big[356[t_{21}(Z_{242-11}*562*12*453*W_{121}+Z_{242-21}*316*16*201*W_{221}+Z_{242-31}*136*17*326*W_{321}+Z_{432-12}*536*12*453*W_{122}+Z_{242-22}*304*16*201*W_{222}+Z_{242-32}*132*17*326*W_{322}+Z_{242-13}*524*12*453*W_{123}+Z_{242-23}*324*16*201*W_{223}+Z_{242-33}*134*17*326W_{323}+48+\ 100)]\Big]$$

$$+y_{24}\Big[356[t_{21}(Z_{242-11}*562*12*453*W_{121}+Z_{242-21}*316*16*201*W_{221}+Z_{242-31}*136*17*326*W_{321}+Z_{432-12}*536*12*453*W_{122}+Z_{242-22}*304*16*201*W_{222}+Z_{242-32}*132*17*326*W_{322}+Z_{242-13}*524*12*453*W_{123}+Z_{242-23}*324*16*201*W_{223}+Z_{242-33}*134*17*326W_{323}+48+\ 68)]\Big]$$

In this formulation it’s taking in consideration the process starting from supplier number one to plant and the transportation from plan one to dc 1 and dc 2. This formulation is independent from the original paper due to the lack of information. Each of the suppliers (y12, y13, y14, y21, y22, y23, y24) needs to be analyzed if is selected or no this factor is also be added in these formulation.

For the second objective that is the emissions the following formulation is the one that it was used:

$$y_{11}\left[Emmisions\ supplier\left[Emmisions\ transportation\left(Z_{1(raw\ )11(tech)1(pr)}\right.\right.\right.$$
$$\left.\left.\left.\times emission\ transportation\ to\ Dc \times emission\ of\ Dc \times emission\ of\ techlogy\right)\right]\right]$$

Using the same procedure the values are going to be enter into the formula using all the suppliers and the emissions of the product starting from the suppliers until the last emission that is the Distribution Center. All of these values are enter into the program Lingo that is one of the most versatile programs that can help to identify the two main objective values that are cost and environmental emissions.

As previously stated the set of equation were input into the lingo program as show in the (Figure 21) .

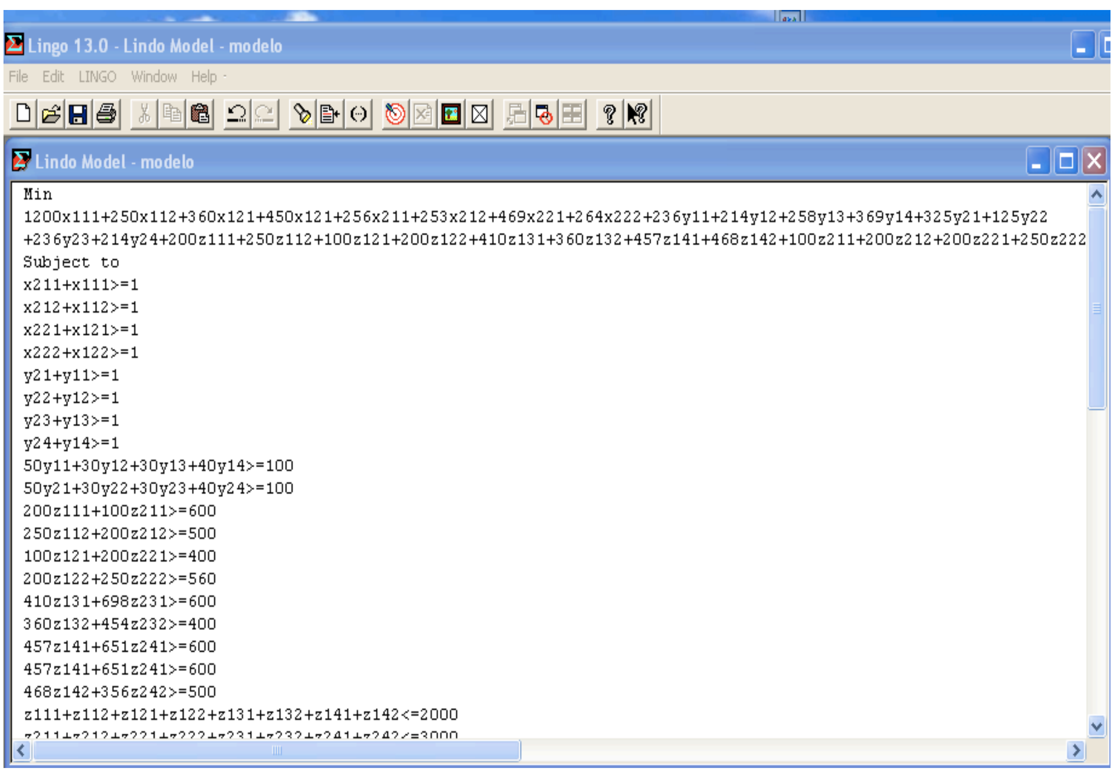

Figure 21. Lingo program

The result that lingo give was for function of cost was 41 677 481 and for emissions 16,800TCO2e.the total variables used are a total of 174,the binary variables 56,the present variables are the following:

t_{12}, t_{22}	*Transportation*
$w_{111}, w_{312}, w_{313}, w_{321}, w_{322}, w_{323}, w_{313}$	*Fixed cost for operating production units*
$z_{111}, z_{112}, z_{111}, z_{211}, z_{212}, z_{121}, z_{221}, z_{132}, z_{231}, z_{232}, z_{141}, z_{142}, z_{241}, z$	*Variable cost for raw materials acquisition*
$y_{11}, y_{12}, y_{13}, y_{14}, y_{21}, y_{22}, y_{23}, y_{24}$	*Suppliers*
$x_{111}, x_{112}, x_{121}, x_{213}, x_{222}, x_{223}$	*Zone location*

Once the emissions and the cost are given. Next step is to identify which one is the biggest or with mayor emissions, then identify it in the supply chain and make a change.

6.8 Application of the framework

As previously state the PDCA framework is going to be applied to this problem, following these steps the framework would be applied to the previous problem.

Step 1. -Plan: Set up an objective and plan an environmental management system implementation. The company need to identify what is the objective enviromental goal to adquire. For this problem the framework will try to minime the mayor emission in the supply chain to identify the source of the problem.

Step 2.. -Do: Implement the new process in the supply chain. Running the problem in lingo, two main objective functions were given.

Analyzing the values of lingo the mayor quantity of emissions was produce in the supplier material 1, plant 1,process 1,technology 3 as show below (Figure 22).

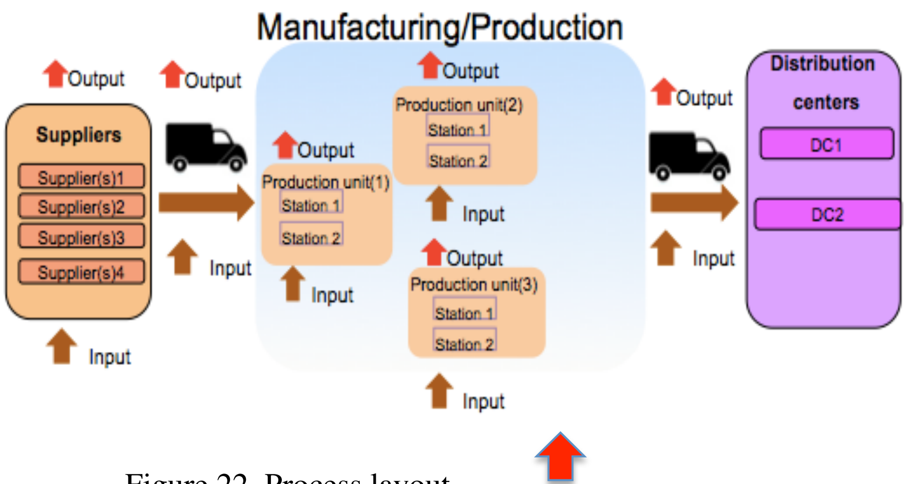

Figure 22. Process layout

In this case the option that give the framework is to apply a plant. For this supplier it can have two options to stop. Lingo gives you the bigger value that you need to look manually, once that the biggest variable, is identify .Is important to make a change, two options are given for this specific problem either eliminate, the process and activate another the second option is to have mayor capacity for each technology in order to reduce the emissions.

In these problem the mayor emission (see Figure 23) was found in the plant 1 process 1 technology 1.this is the one with the biggest emission.

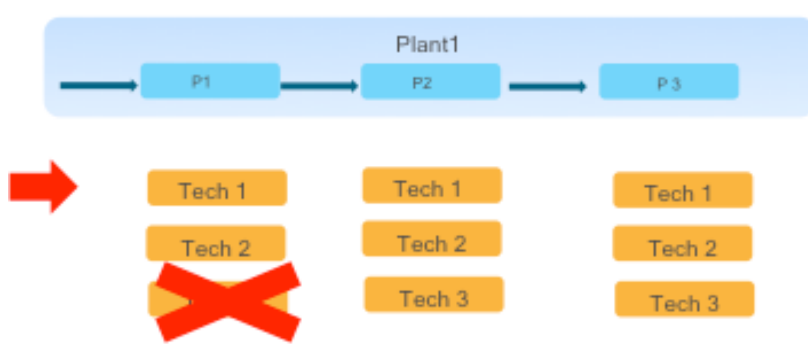

Figure 23.Identifying the mayor emission

Step 3. - Check: Measure the new processes and evaluate environmental performance.

Once that you make that plan you enter the new variables again into the problem for our purposes we obtain the following results.

- 1^{st} run
- F1=$41, 677, 481 dlls
- F2=16,800 tCO2
- 2^{st} run
- F1=$52,900,320 dlls
- F2=16,800 tCO2

As is possible to see this are the changes with eliminating the technology in this step the company will revise this two options and pass to the four step.

Step 4.- Act: Analyze the differences. Finally, this last step analyzes the differences to determine their cause in this case the company decides to eliminate the technology 3 and activating another technology reducing the emissions to air even tough this may have some additional cost. However the use of the PDCA Cycle doesn't necessarily stop there. If you are using the PDCA as continuous improvement initiative, the companies need to loop back to the Plan Phase (Step 1), and seek out further areas for improvement. If the company decides to eliminate the process then they can start all over again the PDCA framework if no they can standardize the activity. One of the good factors of these framework is that is continuously improving.

CHAPTER 7. CONCLUSION

A suitable supply chain system, ensures that production is meet and without any effect in the environment. When the PDCA is used, this provides a useful controlled problem solving process. It is particularly effective for helping implement continuous improvement approaches, when the cycle is repeated again and again as new areas for improvement are sought and solved. Another good benefit of this method is, that it is able to identify new solutions and improvement to processes that are repeated frequently. In this situation, you will benefit from extra improvements built in to the process many times over, once it is implemented. This is done by exploring a range of possible new solutions to problems, and trying them out and improving them in a controlled way before selecting one for full implementation. In comparison with typical frameworks, this helps to avoid the large scale wastage of resources that comes with full scale implementation of a mediocre or poor solution. One of the biggest constrain that this may have is that PDCA is approach is slower and more measured than straightforward. In true emergency situations, this means that it may not be appropriate.

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Vita

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