EVALUATING THE IMPACT OF SUSTAINABILITY AND PIPELINE QUALITY ON GLOBAL CRUDE OIL SUPPLY CHAIN

By

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Abstract

EVALUATING THE IMPACT OF SUSTAINABILITY AND

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SUPPLY CHAIN

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United states is one of the largest crude oil producer in the world but the consumption rate is higher than production hence united states imports oil from varies part of world depend on different criteria.

The objective of this dissertation is to evaluate the impact of pipeline quality and facility sustainability on crude oil supply chain cost for Russia and Colombia that gave idea about when and where we have to invest to satisfy United states oil requirement. In order to meet this objective, three specific criteria are investigated as follow:

1. Evaluate the supply chain factors that determine pipeline quality of crude oil production

2. Evaluate the supply chain factors that determine Sustainability of crude oil production

3. Evaluate the economic impacts of quality and sustainability on operational strategies in supplier network.

The efficiency Curve model is modified to compare Crude oil supply chain among Colombia and Russia based on oil transportation distances and associated cost, refinery costs, and the costs associated with refinery sustainability and pipeline quality shown in

“Modeling the Supply Chain” (Author: Shapiro). However this model was originally used to determine the optimal locations of distribution centers based on transportation cost and the capacity of the distribution centers, this model was modified to allow the use of different costs associated with the quality condition of the pipeline and the sustainability costs of an environmentally friendly facility. This case used to optimize the total cost of oil supply chain for Russia and Colombia. We seek to extend our previous supply chain model, which represent the outbound oil supply chain for Indonesia. The outputs of this paper are efficiency curve that show how the costs of pipeline quality and facility sustainability affect the overall costs of the oil industry of Russia and Colombia.

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Chapter 1

INTRODUCTION

1.1 The United States Dependency on Foreign Oil

The United States of America import oil from different countries, which is essential to sustain American people's necessity based on current situation. The United States imported about 7.7 MMbd of crude oil and 2.1 MMbd of petroleum liquids and refined products in 2013. The United States also exported 3.6 MMbd of crude oil and petroleum products (very little was crude oil), which made the United States a net exporter of petroleum liquids and refined products. Net imports of crude oil and petroleum products (imports minus exports) averaged 6.2 MMbd and accounted for 33% of U.S. total petroleum consumption in 2013, the lowest level since 1986. U.S. dependence on imported petroleum has declined since peaking in 2005.

> This trend is the result of a variety of factors including a decline in consumption and shifts in supply patterns. The economic downturn following the financial crisis of 2008, efficiency improvements, changes in consumer behavior, and patterns of economic growth all contributed to the decline in petroleum consumption. Additionally, increased use of domestic biofuels (ethanol and biodiesel), and strong gains in domestic production of crude oil and natural gas plant liquids expanded domestic supplies and reduced the need for imports (US EIA 2013)

The current U.S. sources for oil is not limited to politically stable countries but it majorly relies on Canada &OPEC member Saudi Arabia. There is a concern about the impact to the U.S. economy if Canada or Saudi Arabia decides to manipulate demand and possibly stops exporting oil to the United States. The dependence on foreign oil does not present strategic challenges to the United States and that it does not negatively affect the nation's economy and national security. This dependency has had a large impact on the U.S. foreign policy and continues to influence international relationships. Today, the consideration is more in regards as to which foreign oil sources are the most challenging and what steps could be taken by the U.S. government to help alleviate these challenges.

1.1.1 Problem Statement

According to U.S. EIA , About 27% of the petroleum consumed by United States was imported from foreign countries. Our main problem is dependency on Middle Eastern country for petroleum, If the refuse to export the petroleum to United states, that will affect the U.S. economy and United States has to identify Substitute for petroleum products.

The U.S. EIA stated that the U.S. consumed an estimated 18.96 million barrels per day (MMbd) of petroleum products and produced 12.31MMbd of crude oil and petroleum products during 2013. Therefore, the U.S. net imports of crude oil and petroleum products equaled 6.57MMbd, making the U.S. dependent on foreign oil – see Figure 1

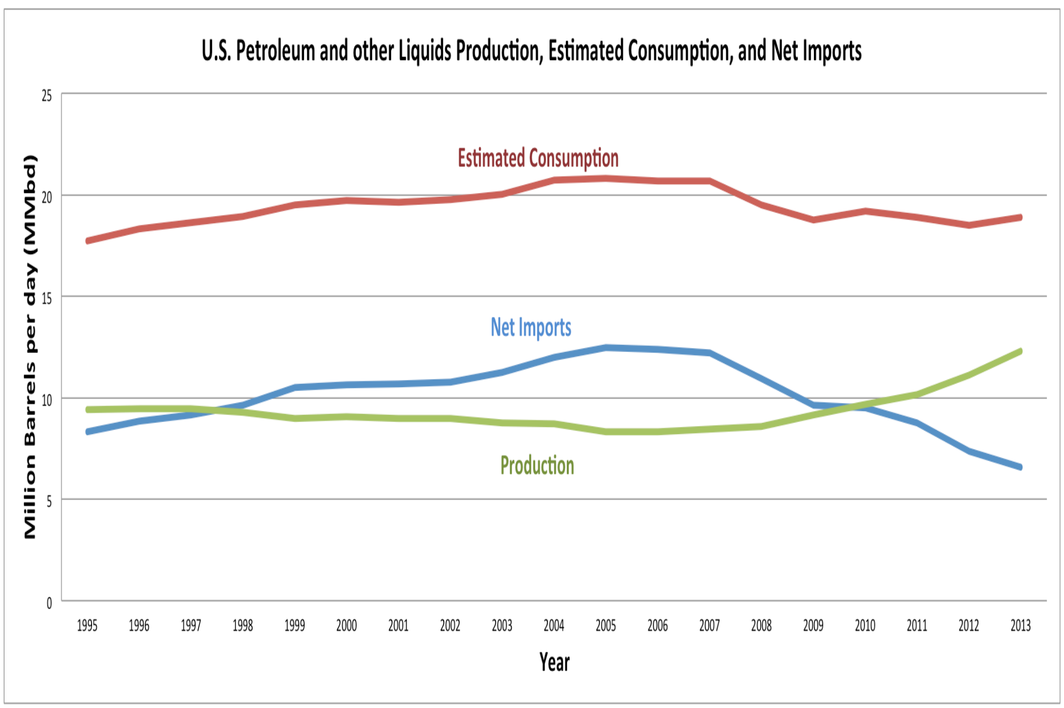


Figure 1 US Petroleum and other liquid Production, Estimated Consumption & net imports from 1995-2013. Preliminary Data: U.S.EIA Oct 2014

Most of the imports came from the western hemisphere. The Western hemisphere including North, South, and Central America, the Caribbean, and the U.S. territories; and the Persian Gulf countries such as Iraq, Kuwait, Qatar, Saudi Arabia, and United Arab Emirates, exported 55.8 percent and 31.8 percent, respectively of crude oil and petroleum products to the U.S. in 2013 .

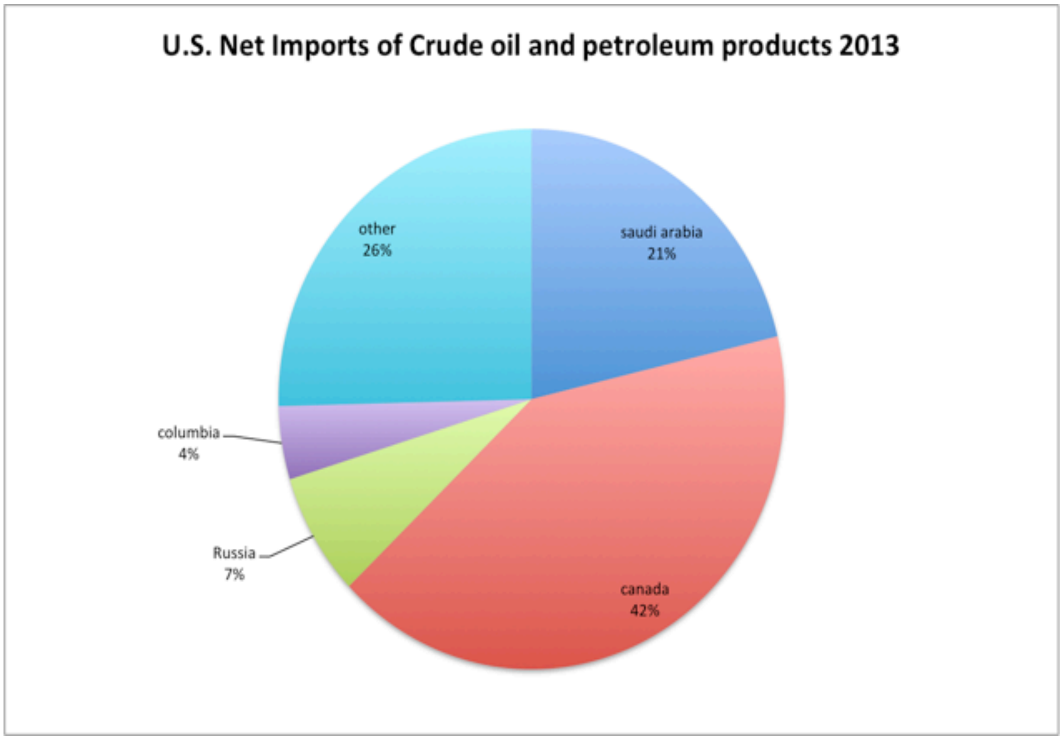


Figure 2 U.S. Net Imports of Crude Oil and Petroleum Products from Saudi Arabia, Canada, Russia and Colombia in 2013. Preliminary Data: U.S. EIA, October 2014.

Imported Oil from Canada and Saudi Arabia accounted for 42 percent and 21 percent, respectively, of the U.S. crude oil and petroleum products imports, resulting in those countries representing the top two foreign oil sources for the U.S. in 2013 – see Figure 2

1.1.2 Research Significance

This is significantly an issue that 21 percent of the U.S. net crude oil and petroleum products imports come from one country, Saudi Arabia, which threatens U.S.

homeland security by leaving the U.S. susceptible to Middle Eastern manipulation. While the U.S. does import a larger percentage of crude oil and petroleum products from Canada, Canada is considered an ally due to treaties signed during World War II and during the Cold War.

According to US EIA, oil from Russia and Colombia is approximately 7 percent and 4 percent of the US crude oil and petroleum product respectively. -See figure 2

The significance of this research is to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that identifies how other nations such as Russia and Colombia can be more efficient in their crude oil supply chain and produce more crude oil products for export. This model was built with respect to the trade-off between crude oil supply chain quality, sustainable environmental incentives, and supply chain costs. Furthermore, the broader impact is how investments into other countries crude oil supply chains can be quantified and optimized and how countries such as Russia and Colombia can be identified as possible candidates for investment for future global crude oil needs. This paper hypothesizes that the crude oil supply chain quality will impact the crude oil supply chain costs. Additionally, the environmental sustainability will have an impact on crude oil supply chain costs, and suggests that the crude oil supply chains of each of these countries will dictate their ability to produce crude oil for export. The overall objective is to investigate a mixed-integer programming (MIP) model that supports decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil so that it becomes more cost effective for the U.S. to import crude oil from other nations as opposed to other global sources.

1.1.3 Research questions and Hypothesis

The U.S. Government , crude oil refining companies and other stake holders find it necessary to invest infrastructure and to buy crude oil from other nation to accomplish the requirement of US. Therefore, this dissertation attempt to answer the following Global question. " When is it economically benefit to invest in supply chain of crude oil for given nation?". This question hypothesizes that the pipe line quality and sustainability will impact the supply chain cost, and suggest that the crude oil supply chain for given nation will dictate their ability to be a better candidate for investment.

1.2 Research Purposes

The goal of the most of companies is to maximize profit and shareholder value. In the oil industry, to maximize of shareholder value, the value of oil resources should be maximized through managing production, exploration, and development activities to assure a functioning market. (pirog 2007),Reserve replacement and ability to expand production and sales to meet demand are important activities to ensure the long-term feasibility of company. Technical efficiency is required to minimize cost, to improve performance and environmental integrity.

The management of the company organizing production to accomplish goal, which help to made profit in current as well as future time. Management make investment decision to raise company's rate of return and to increase he profitability.

A majority of government operate their national oil companies so this companies do not follow stakeholder value maximization model. They have to compete with governmentally mandated objectives to maximize the value of the company. These companies have pressure to maximize the flow of fund to national treasuries.

There are several example of unsuccessful deals between national oil companies in which the outcomes was not able to meet expectations like “China & Iran” and “China & Saudi Arabia”.

Furthermore, the broader impact is how investments into other countries crude oil supply chains can be quantified and optimized and how countries such as Russia/Colombia can be identified as possible candidates for investment for future global crude oil needs.

We chose Russia and Colombia as a selected candidate for the research due to following criteria. From the data, net export for Russia and Colombia is significantly impressive and looks like we can find a better candidate for investment and both the countries have economical and productive oil refinery.

This paper hypothesizes that the crude oil supply chain quality will impact the crude oil supply chain costs. Additionally, the environmental sustainability will have an impact on crude oil supply chain costs, and suggests that the crude oil supply chains of each of these countries will dictate their ability to produce crude oil for export. The overall objective is to investigate a mixed-integer programming (MIP) model that supports decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil, specifically in Russia/Colombia so that it becomes more cost effective for the U.S. to import crude oil from Russia/Colombia as opposed to other global sources.

Chapter 2

BACKGROUND

2.1 Crude Oil and Petroleum Product

2.1.1 Crude Oil formation

Crude oil, commonly known as petroleum, was formed from the remains of animals and plants (called biomass) that lived many years ago. Over many years the biomass was covered by layers of mud, silt, and sand that formed into sedimentary rock. Geologic heat and the pressure of the overlying rock turned the biomass into a hydrocarbon-rich liquid that we call crude oil, and eventually forced it into porous rock strata called reservoirs. Oil reserves cannot be reproduced because it needs millions of years to form. That's why crude oil is called non-renewable energy source. There are also formations or deposits of hydrocarbon-saturated sands and shale where geologic conditions have not been sufficient to turn the hydrocarbons into liquid. (see fig 3)

Crude oil is a liquid found within the Earth comprised of hydrocarbons, organic compounds and small amounts of metal, While hydrocarbons are usually the primary component of crude oil, their composition can vary from 50%-97% depending on the type of crude oil and how it is extracted. Organic compounds like nitrogen, oxygen, and sulfur typically make-up between 6%-10% of crude oil while metals such as copper, nickel, vanadium and iron account for less than 1% of the total composition.

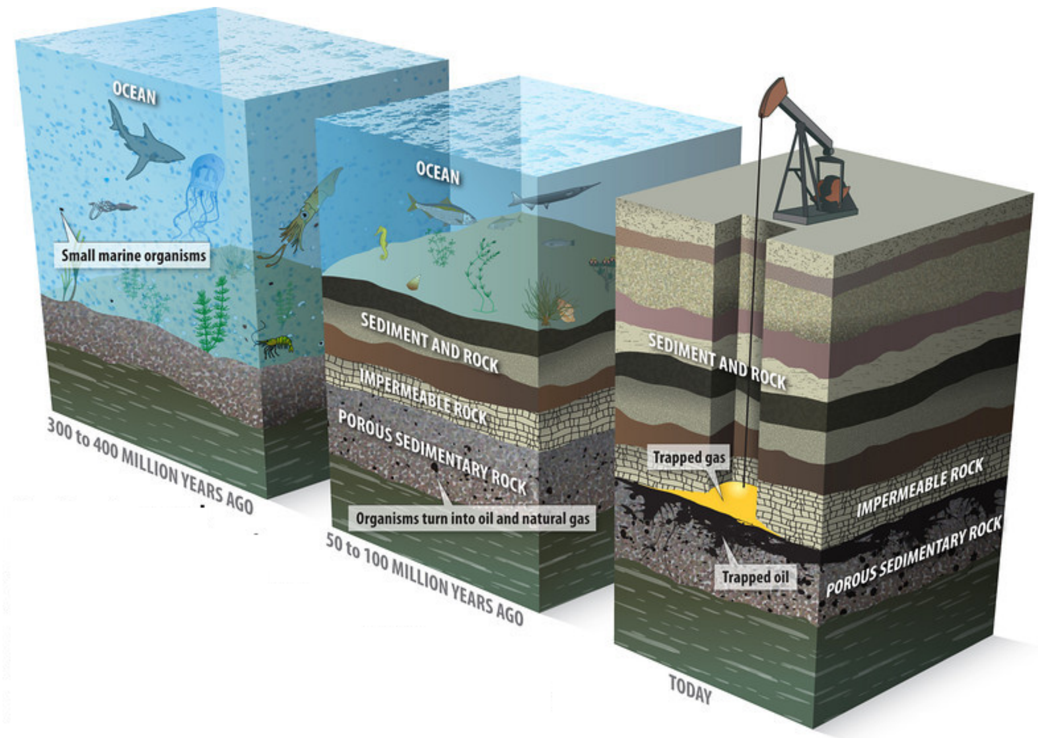


Figure 3 Crude oil and natural Gas formation process

Source: Need project-petroleum Jan 17,2013

2.1.2 Crude oil Exploration

Petroleum has been used since ancient time. Geologists observe rock structure and its characteristics to determine the oil reservoir. According to E-tech international, oil exploration and production processes consist of five main processes.

Figure 4 Crude Oil Exploration Process

2.1.2.1 Exploration

Oil and gas exploration is the discovery for hydrocarbon deposits (oil and gas) underneath the Earth's surface by petroleum geologists and geophysicists. It contains locating oil and gas reservoirs using primarily seismic surveys and drilling wells.

Exploration is an expensive, high-risk operation because it costs millions of dollars and every one out of three wells, on average, contain hydrocarbons. Therefore companies have to drill multiple wells in one area before finding an oil or gas, which can take several years.

During exploration drilling, information and samples are collected about the rocks and fluids (water, gas and oil) from the well which lead to following info:

- Whether there are any hydrocarbons at that location
- How much oil or gas might be present
- What depth the oil or gas occurs at

Exploration activities can also be risky because of:

- The location - remote or difficult terrain, or a sensitive ecosystem
- Safety - people can have accidents while obtaining seismic surveys or drilling wells, even though safety is always a top priority

2.1.2.2 Appraisal

If a company is successful with their exploration drilling and make an oil or gas discovery, then they move into the appraisal phase of the lifecycle. The purpose of this phase is to reduce the uncertainty about the size of the oil or gas field and its properties.

During appraisal, more wells are drilled to collect information and samples from the reservoir. Another seismic survey might also be acquired in order to better image the reservoir. These activities can take several more years and cost tens to hundreds of millions of dollars.

More seismic surveys and wells help petroleum geologists; geophysicists and reservoir engineers understand the reservoir better. For example, they try to find out whether rock or fluid properties change away from the discovery well, how much oil or gas might be in the reservoir, and how fast oil or gas will move through the reservoir.

The appraisal stage is successful if a company decides that the oil or gas field can be developed. One risk that companies face is even after investing time and money in the appraisal stage, they might not find a way to develop the field safely, profitably and responsibly (in terms of communities and the environment).

2.1.2.3 Development

The development stage takes place after successful appraisal and before full-scale production. The main activities (and people involved) are :

- To form a plan to develop the oil or gas field, including how many wells need to be drilled to produce the oil or gas (geologists, geophysicists and reservoir engineers)
- To decide the best design for the production wells (drilling engineers)
- To decide what production facilities are required to process the oil/gas before it is sent to a refinery or customer (facilities engineers)
- To decide what the best export route might be for the oil and gas (logistics engineers)

Executing the development plan involves drilling engineers who drill the first phase of production wells and project engineers who build the planned facilities. Many thousands of people can be involved in building production facilities, and safety is a top priority. The risk of accidents is highest in this phase because of the number of people involved at construction sites.

It costs hundreds of millions, sometimes billions of dollars and typically 5-10 years to develop an oil or gas field, depending on the location, size and complexity of the facilities, and the number of wells needed. Onshore developments are typically much cheaper than offshore developments.

No oil or gas field will be developed unless the company believes that they will make enough money to pay back their exploration, appraisal and development costs, as well as profit from selling the hydrocarbons. Even more importantly, developments will only happen if the communities or ecosystems affected can be protected.

2.1.2.4 Production

Production is the phase during which hydrocarbons are extracted from an oil or gas field and the first money (or revenue) comes from selling the oil or gas. After a number of years, the revenue exceeds the company's investment and they begin to make a profit.

Production can last several years up to 40 years, depending on the size of the oil or gas field and how expensive it is to keep the wells and production facilities running. Every year millions of dollars will be spent on operating and maintaining the field. Safe production operations is critical, otherwise companies risk harming people or the damaging the environment, e.g. through an oil spill, or explosion.

Operators work in shifts to keep production going. Engineers will usually be located full-time at the production facilities in order to operate and maintain them. Reservoir engineers will check on the health and performance of the field to plan how best to maintain production. Additional wells might need to be drilled or the production facilities improved to maximize recovery of the oil or gas.

2.1.2.5 Decommissioning

Decommissioning is the term used for removing the production facilities and restoring oil and gas sites that are no longer profitable. The term is usually used to refer to offshore facilities. Offshore oil and gas platforms can be vast structures requiring large amounts of materials in their construction. By bringing the facilities onshore for dismantling and disposal, these materials can be reclaimed.

Decommissioning not only involves removing the main platform, but pipelines and cables as well. The aim is to reduce the risk to the marine environment and to reuse or recycle materials. In the majority of cases, all equipment is removed and the site returned to its condition before development began. Some installations can be reused as oil and gas facilities at another location or reused in place for another purpose (e.g., as a wind farm or aid to navigation). Occasionally, part of the platform may be left in place because they benefit the marine environment, e.g., steel legs of tension leg platforms that are used to create artificial reefs in the Gulf of Mexico.

Project, logistics and environmental engineers will be involved in decommissioning a production facility. This vital step takes several years and many millions of dollars. Government requirements and community views will be taken on board during decommissioning.

2.1.3 Crude Oil Extraction

Extracting oil and natural gas from oil field isn't as simple as just drilling and completing a well. Crude oil extraction process consist of three recovery process .(see figure 5 and 6)

2.1.3.1 Primary Recovery

When an oil field is first produced, the oil typically is recovered as a result of expansion of reservoir fluids which are naturally pressured within the producing formation. The only natural force present to move the oil through the reservoir rock to the wellbore is the pressure differential between the higher pressure in the rock formation and the lower pressure in the producing wellbore. Various types of pumps are often used to reduce pressure in the wellbore, thereby increasing the pressure differential. At the same time, there are many factors that act to impede the flow of oil, depending on the nature of the formation and fluid properties, such as pressure, permeability, viscosity and water saturation. This stage of production, referred to as "primary recovery," recovers only a small fraction of the oil originally in place in a producing formation, typically ranging from 10% to 25%.

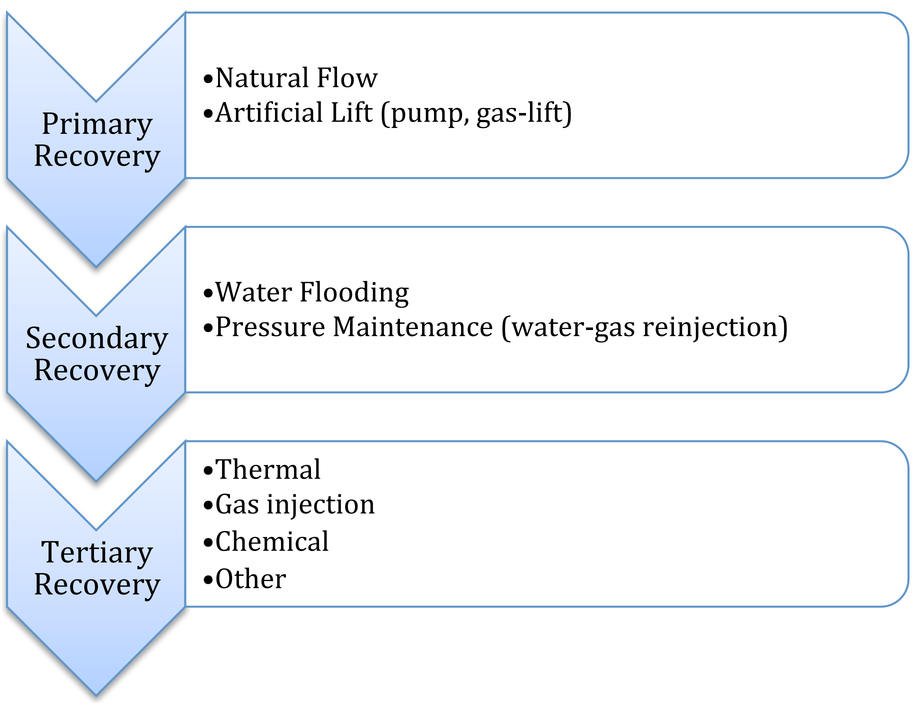


Figure 5 Crude Oil Extraction Process

Primary recovery first relies on underground pressure to drive fluids to the surface. When the pressure falls, artificial lift technologies, such as pumps, are used help bring more fluids to the surface. In some situations, natural gas is pumped back down the well underneath the oil. The gas expands, pushing the oil to the surface. Gas lift technology is often used in offshore facilities. Primary recovery often taps up to 15 percent of the oil in a deposit.

2.1.3.2 Secondary Recovery

After the primary recovery phase many, but not all, oil fields respond positively to "secondary recovery" techniques in which external fluids are injected into a reservoir to increase reservoir pressure and to displace oil towards the wellbore. Secondary recovery techniques often result in increases in production and reserves above primary recovery. Water flooding, a form of secondary recovery, works by repressing a reservoir through water injection and "sweeping" or pushing oil to producing wellbores. Through water flooding, water injection replaces the loss of reservoir pressure caused by the primary production of oil and gas, which is often referred to as "pressure depletion" or "reservoir voidage." The degree to which reservoir voidage has been replaced through water injection is known as "reservoir fill up" or, simply as "fill up." A reservoir which has had all of the produced fluids replaced by injection is at 100% fill up. In general, peak oil production from a water flood typically occurs at 100% fill up. Estimating the percentage of fill up which has occurred, or when a reservoir is 100% filled up, is subject to a wide variety of engineering and geologic uncertainties. As a result of the water used in a water flood, produced fluids contain both water and oil, with the relative amount of water increasing over time. Surface equipment is used to separate the oil from the water, with the oil going to pipelines or holding tanks for sale and the water being recycled to the injection facilities. In general, in the Mid-Continent region, a secondary recovery process may produce an additional 10% to 20% of the oil originally in place in a reservoir.

2.1.3.3 Tertiary recovery

A third stage of oil recovery is called "tertiary recovery." In addition to maintaining reservoir pressure, this type of recovery seeks to alter the properties of the oil in ways that facilitate additional production. The three major types of tertiary recovery are chemical flooding, thermal recovery (such as a steam flood) and miscible displacement involving carbon dioxide (CO_2), hydrocarbon or nitrogen injection.

Thermal recovery entails injecting steam into the formation. The heat from the steam makes the oil flow more easily, and the increased pressure forces it to the surface.

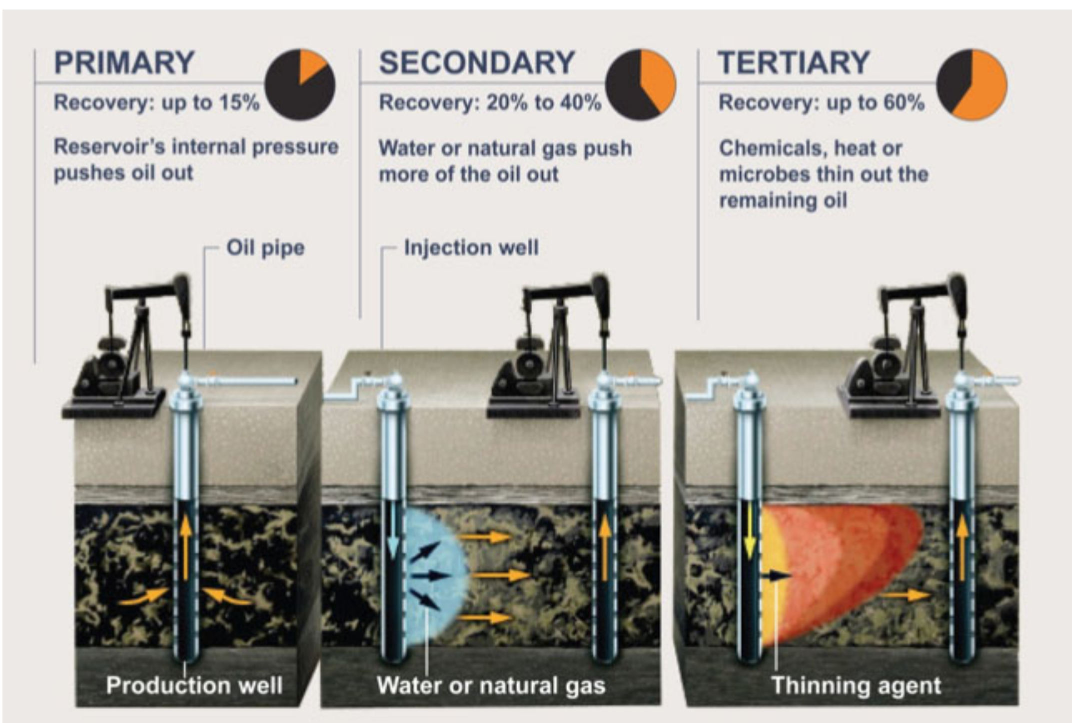


Figure 6 Three Stages of Recovery

Source: “squeezing more oil from ground” scientific American 2009 by Maugeri

Gas injection uses either miscible or immiscible gases. Miscible gasses dissolve CO_2, propane, methane or other gasses in the oil to lower its viscosity and increase flow. Immiscible gasses do not mix with the oil, but increase pressure in the “gas cap” in a reservoir to drive additional oil to the well bore.

Chemical flooding involves mixing dense, water-soluble polymers with water and injecting the mixture into the field. The water pushes the oil out of the formation and into the well bore.

We are currently field testing new technologies in chemical flooding on some of our properties. If successful, this testing may lead to reserve and production increases in the future. Any future tertiary development programs and subsequent capital expenditures would be contingent upon commercial viability established by successful pilot testing. At this time there are no estimated reserves or production associated with tertiary recovery projects assigned to our properties. We will continue to review future opportunities for growth through the use of various tertiary recovery techniques.

2.2 Oil Refinery and Transportation

A crude oil refinery is a group of industrial facilities that turns crude oil and other inputs into finished petroleum products. A refinery's capacity refers to the maximum amount of crude oil designed to flow into the distillation unit of a refinery, also known as the crude unit.

2.2.1 Crude oil distillation

Crude oil is unprocessed oil, which comes out of a ground. Refineries process crude oil into many different petroleum products. These products include gasoline, diesel fuel, jet fuel, and asphalt. The most basic refining process separates crude oil into its various components. The various components of crude oil have different sizes, weights and boiling temperatures. The process is very complex and involves both chemical reactions and physical separations. Crude oil is composed of thousands of different molecules. It would be nearly impossible to isolate every molecule and make finished products from each molecule. Chemists and engineers deal with this problem by isolating mixtures of molecules according to the mixture's boiling point range. Crude oil is heated and put into a distillation tower (a still) where different hydrocarbon components are boiled off and recovered as they condense at different temperatures. (see figure 7)

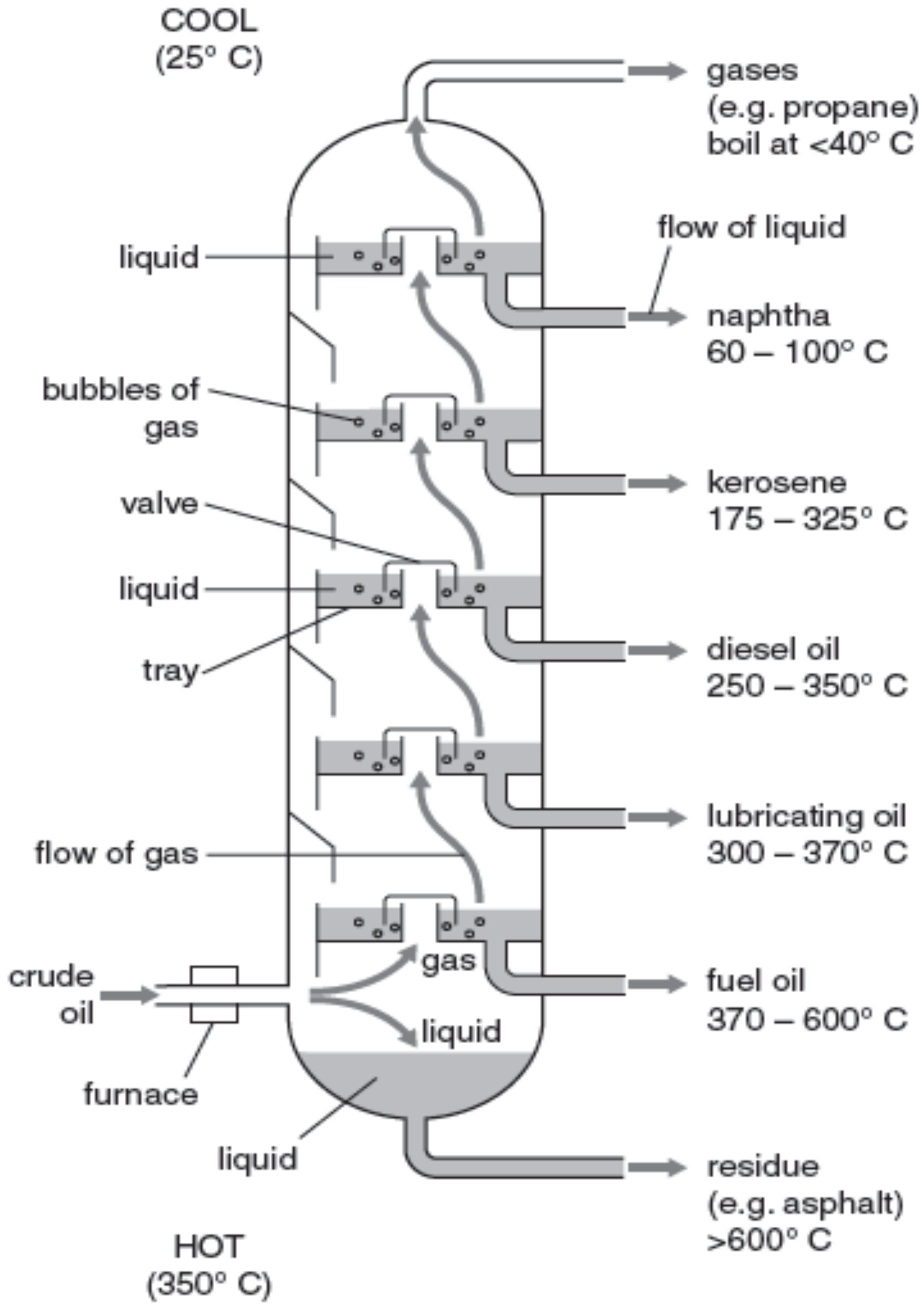


Figure 7 Crude Oil Distillation Process

The major products of crude oil according to its specific temperature are as follow:

Table 1 Crude Oil Products

Product Name	Boiling Range	State	Uses
Petroleum Gas	40 degree Celsius	Gas	Used for heating, cooking
Naphtha	60 to 100 degree Celsius	Gas	Intermediate that will be processed more to make gasoline
Gasoline	40 to 205 degree Celsius	Liquid	Motor Fuel
Kerosene	175 to 325 degree Celsius	Liquid	Fuel for jet engine and tractors
Diesel oil	250 to 350 degree Celsius	Liquid	Used for diesel fuel and heating oil
Lubricating oil	300 to 370 degree Celsius	Liquid	Used for motor oil, grease and other lubricant
Fuel oil	370 to 600 degree Celsius	Liquid	Used for industrial fuel
Residuals	Above 600 degree Celsius	Solid	Coke, asphalt, tar, waxes etc.

2.2.2 Crude oil transportation

Oil transportation is a major industry in and of itself, with a range of transportation options available, depending on the situation at hand. The most important methods include pipeline, rail, barge and truck. Transportation and storage in the oil and gas industry concerns to the movement of crude oil from the oil fields (where oil has been discovered) to petroleum refineries (where the oil is further processed) to storage areas, where the petroleum products are stored for distribution and emergency reserves.

Advances in exploration and production have helped to locate and recover a supply of oil and natural gas from major reserves across the globe. At the same time, demand for petroleum-based products has grown in every corner of the world. But supply and demand are rarely concentrated in the same place. Transportation therefore is vital to ensuring the reliable and affordable flow of petroleum we all count on to fuel our cars, heat our homes and improve the quality of our lives.

there are four mode of transportation associated with crude oil .

2.2.2.1 Ship and Barge

Oil tankers ship are used for oil transport overseas or from sea to shore. Tankers can carry huge amounts of oil, and they have the flexibility of being able to transport to a variety of locations, whereas pipelines have fixed networks and limited ranges. As the name implies, tankers store large quantities of oil in enormous tanks on the ship.

Unlike oil tankers ship, barges are used to transport oil in barrels. This allows for easy loading and unloading of measured units of oil.

Advantage of Ship and barge:

- Capitalizes on existing infrastructure for receiving marine shipment at coastal refineries

Figure 8 Oil Tanker Ship : Souce : gulf times, business week sept 5, 2011

Disadvantage of ship and barge:

- Impact of day to day unconventional crude transit still unknown, increased vessel traffic

2.2.2.2 Pipeline

Oil pipelines are the most efficient means of transporting oil. They can handle enormous amounts of oil day in and day out with very little human interaction, and they can cover enormous distances.

Advantages of pipelines:

- Cost affective form of transit for producer
- Income incentives for landowners

Figure 9 Oil Pipeline Source : Dispatchcrude.com

Disadvantages of Pipeline

- Distraction to agriculture and other land uses from construction and operation
- Difficulties associated with land restoration

2.2.2.3 Rail

Trains are useful for transporting large amounts of oil over land and can generally reach a wider network of locations than oil pipelines can.

Advantages of rail:

- increased flexibility for producer and refiner
- infrastructural benefit

Figure 10 Rail Source: Energy News Roundup jan 2014

Disadvantage of Rail:

- crowding out rail network access by other industries
- Functionality and safety can be affected by adverse weather

2.2.2.4 Truck

Trucks are the most limited oil transportation method in terms of storage capacity, but they have the greatest flexibility in potential destinations. This means trucks are often the last step in the transport process, delivering oil and refined petroleum products to their intended storage destinations.

Advantage of Truck:

- Ideal for short distance but can be used for long hauls

Figure 11 Truck Source: Hetanch Truck

Disadvantage of truck:

- Road traffic Congestion and infrastructure damage

2.2.3 Crude oil Waste

The United States Environmental Protection Agency (EPA) classifies crude oil waste into following two categories. 1). Exempt and 2.) Non-exempt wastes.

The EPA defines exempt wastes as follow:

"Wastes that are generated before the end point of primary field operations are exempt. The term end point of initial product separation means the point at which crude oil leaves the last vessel in the tank battery associated with the wells. This tank battery separates crude oil from the produced water and/or gas" .

With respect to crude oil, primary field operations include activities occurring at or near the wellhead and before the point where the oil is transferred from an individual field facility or a centrally located facility to a carrier for transport to a refinery or a refiner.

Primary field operations include exploration, development, and the primary, secondary, and tertiary production of oil or gas. Crude oil processing, such as water separation, de- emulsifying, degassing, and storage at tank batteries associated with a specific well or wells, are examples of primary field operations. Furthermore, because natural gas often requires processing to remove water and other impurities prior to entering the sales line, gas plants are considered to be part of production operations regardless of their location with respect to the wellhead.

List of Exempt and non – exempt for Crude oil E&P

2.2.3.1 Exempt Waste

- Produced water
- Drilling fluids
- Drill cuttings
- Rig wash
- Drilling fluids and cuttings from offshore operations disposed of onshore
- Geothermal production fluids
- Hydrogen sulfide abatement wastes from geothermal energy production
- Well completion, treatment ,and stimulation fluids
- Basic sediment, water, and other tank bottoms from storage facilities that hold product and exempt waste

- Accumulated materials such as hydrocarbons, solids, sands, and emulsion from production separators, fluid treating vessels, and production impoundments
- Pit sludge's and contaminated bottoms from storage or disposal of exempt wastes
- Gas plant dehydration wastes, including glycol-based compounds, glycol filters, and filter media,
- backwash, and molecular sieves
- Work over wastes
- Cooling tower blow down
- Gas plant sweetening wastes for sulfur removal, including amines, amine filters, amine filter media, backwash, precipitated amine sludge, iron sponge, and hydrogen sulfide scrubber liquid and sludge
- Spent filters, filter media, and backwash (assuming the filter itself is not hazardous and the residue in it is from an exempt waste stream)
- Pipe scale, hydrocarbon solids, hydrates, and other deposits re moved from piping and equipment prior to transportation
- Produced sand
- Packing fluids
- Hydrocarbon-bearing soil
- Pigging wastes from gathering lines
- Wastes from subsurface gas storage and retrieval
- Constituents removed from produced water before it is injected or otherwise disposed of

- Liquid hydrocarbons removed from the production stream but not from oil refining
- Gases from the production stream, such as hydrogen sulfide and carbon dioxide, and volatilized hydrocarbons
- Materials ejected from a producing well during blow down
- Waste crude oil from primary field operations
- Light organics volatilized from exempt wastes in reserve pits, impoundments, or production equipment

2.2.3.2 Non-Exempt Waste

- Unused fracturing fluids or acids
- Gas plant cooling tower cleaning wastes
- Painting wastes
- Waste solvents
- Oil and gas service company wastes such as empty drums, drum reinstate, sandblast media, painting wastes, spent solvents, spilled chemicals, and waste acids
- Vacuum truck and drum reinstate from trucks and drums transporting or containing non-exempt waste
- Refinery wastes
- Liquid and solid wastes generated by crude oil and tank bottom reclaimers
- Used equipment lubricating oils
- Waste compressor oil, filters, and blow down
- Used hydraulic fluids

- Waste in transportation pipeline related pits (except with approval by NDDH)
- Caustic or acid cleaners
- Boiler cleaning wastes
- Boiler scrubber fluids, sludge, and ash
- Incinerator ash
- Laboratory wastes
- Sanitary wastes
- Pesticide wastes
- Radioactive tracer wastes
- Drums insulation, and miscellaneous solids

2.2.4 Pipeline Quality Factors

Pipelines are not part of primary field operations, thus, oil wastes that are generated by pipelines are non-exempt. Failure of a pipeline segment caused by accidental excavation damage is an example of non-exempt wastes, which will result in oil companies paying fines to the EPA as well as settlements to clean the surrounding environment. This pipeline segment failure is chosen as the sampling plan of supply chain quality level performance.

following table shows summary of various causes for pipeline failure:

Table 2 Causes for pipeline failure

Type of failure	Causes
Mechanical Failure	Construction, Material and Structural
Corrosion	Internal, External
Operational failure	System , Human
Third-party activity	Accidental, Malicious, Incidental
Natural Hazard	Subsidence, flooding , earthquake etc.

Pipeline quality affect the transportation cost for crude oil . Cause and effect diagram for pipeline loss shown below:

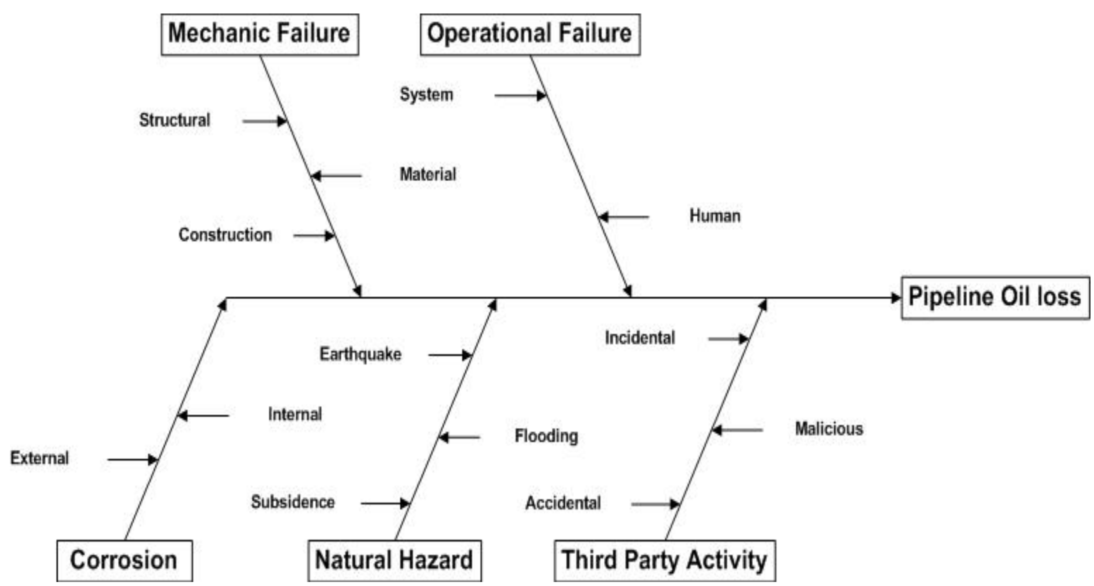


Figure 12 Cause & Effect Diagram For pipeline loss

2.2.5 Refinery Sustainability

Globalization has resulted in pressure on multinational firms to improve environmental performance. In order to achieve improvement in environmental performance, a company must integrate its environmental management strategies, while maintaining production quality and cost goals, into the supply chain, which includes all of the operational life cycle stages such as unique partnerships with suppliers. Environmental sustainability has been defined as “meeting the needs of the present without compromising the ability of the future generations to meet their needs” [UN Document].

For oil companies, the concept of sustainability is most appropriately used when evaluating their business strategies. Sustainability concerns are to the degree of which they will not only reduce negative impacts on the natural environment through their operations, but also invest in business practices that promote policies to make wide reaching progress toward sustainable development. In the industry, the operations of oil companies are examined for their impact on the surrounding environment annually. To distinguish from the above definition of sustainability, environmentally conscious operations are referred to as green operations. However, green operations are not necessarily sustainable in the long run, but minimizing the negative impact of operational processes is still environmentally conscious. Company operations deal with energy usage necessary for operating refineries, emissions, and waste. Meanwhile, sustainability of the products deals with oil, natural gas, and possible alternatives to fossil fuels.

In the oil industry exploration and production processes, sustainability involves the products, and as such, the petroleum industry itself is environmentally unsustainable because like all fossil fuels, oil is a limited resource. Some risks of accidental spills of oil have the potential to pollute water, contaminate soil, harm species, and affect livelihoods.

Oil companies need to plan all major operations in advance and manage their costs during the supply chain to improve the profit margin. Sustainability that associated with oil companies' processes or products will have positive and negative impacts on the supply chain costs. An example of the negative impact is certainly the tragic British Petroleum (BP) drill explosion and oil spill in 2010, which impacted nature and animals in the Gulf of Mexico. This accident resulted in damaging the environment as well as costing BP a settlement of billions of dollars. Contrary, an example of the positive impact is the ability to be capable to reserve the productivity of oil itself as a natural resource asset, which leads to supply chain costs savings.

Unlike the quality metrics, which focused on pipelines performance, this research considers refining process as a good candidate to determine its sustainability metrics. Refinery is a complex process. Oil refineries essentially serve as the second stage in the production process following the actual extraction by oilrigs. The first step in the refining process is distillation where crude oil is heated at extreme temperatures to separate the different hydrocarbons. The refining sector of the oil industry has significantly affected the crude oil global marketplace due to the demand growth of petroleum products. As the petroleum products demand increases, the demand for conversion capacity increases. Refineries affect supply chain profit margins such that refineries' variable costs depend on the petroleum products demand.

There are two sustainability factors that are considered for refineries performance. The first factor is the refining operations, which deal with energy usage necessary for operating refineries, emissions, and waste. The second factor is the refining products, which deal with oil to fossil fuels. Refining processes that deal with energy usage are chosen as environmental sustainability according to the performance-sampling plan

2.3 Oil Industry

2.3.1 Russia

The petroleum industry in Russia is one of the largest industries in the world. Russia was the third-largest producer of liquid fuels in 2012, following the United States and Saudi Arabia. Russia's proven oil reserves were 80 billion barrels as of January 2013, according to the *Oil and Gas Journal*. In 2012, Russia produced an estimated 10.4 million bbl./d of total liquids (of which 9.9 million bbl/d was crude oil), and it consumed roughly 3.2 million bbl/d. Russia exported over 7 million bbl/d in 2012, including roughly 5 million bbl/d of crude oil and the remainder in products. (“Russia”, 2013)

Figure 13 Russia Map Source : U.S. EIA

Most of Russia's oil production continues to originate in West Siberia, notably from the Preobskoye and Samotlor fields. Approximately 62% of oil produced from West Siberia region while nearly 22% oil produced from Urals-Volga region. The use of more advanced technologies and the application of improved recovery techniques are resulting in increased oil output from existing oil deposits. Fields in the Western Siberian Basin produce the majority of Russia's oil, with developments at the Samotlor (TNK-BP) and Priobskoye (Rosneft) fields extracting more than 750,000 bbl/d and 800,000 bbl/d, respectively. Russian firms govern the region, although foreign companies, notably Shell, have secured access to production in Western Siberia as well.

West Siberia is Russia's main oil producing region, accounting for around 6.4 million bbl/d of liquids production, nearly two-thirds of Russia's total production. While this region is mature, West Siberian production potential is still significant but will depend on improving production economics at fields that are more complex and that contain a significant portion of remaining reserves. The two largest oil fields in West Siberia are North Priobskoye and Samotlor, which account for about 20% of West Siberian production. Urnegoy is the largest gas field in the region.

Urals-Volga was the largest producing region of the Soviet Union until the late 1970s, when it was surpassed by Western Siberia. Today, this region is a distant-second producing region, accounting for about 22% of Russia's total output. The giant Romashkinskoye field (discovered in 1948) is the largest in the region. Tatneft operates it, While the field reached its peak production level sometime in the late 1970s, it likely will continue to produce until at least 2030, according to Wood Mackenzie.

The potential oil reserves of Eastern Siberia, the Russian Arctic, the northern Caspian Sea, and Sakhalin Island are attracting attention. Russian companies are also expanding into the Arctic and Eastern Siberian regions, prompted on by tax holidays and lower oil export tariffs. While several new fields have come on line since 2009, bringing additional fields into production will take time and may require an improved oil tax system from the government.

Russia has 40 oil refineries with a total crude oil distillation capacity of 5.5 million bbl/d, according to Oil and Gas Journal. Rosneft, the largest refinery operator, has a crude distillation capacity of 1.3 million bbl/d and operates Russia's largest refinery, the Angarsk facility. LUKoil is the second-largest operator of refineries in Russia with a crude distillation capacity of 1 million bbl/d.

In 2012, Russia exported approximately 7.4 million bbl/d of total liquid fuels, with 5 million bbl/d of crude oil and 2.4 million bbl/d of petroleum products. The majority (79%) of Russia's crude oil exports went to European countries (including Eastern Europe), particularly Germany, Netherlands, and Poland. Around 18% of Russia's crude oil exports were destined for Asia, while the remainder went mostly to the Americas. Russia's crude oil exports to North America and South America have been largely displaced by increases in crude oil production in the United States, Canada, and, to a lesser extent, in Brazil, Colombia, and other countries on the continent. More than 80% of Russia's oil is exported via the Transneft pipeline system, and the remainder is shipped via rail and on vessels that load at independently owned terminals.

Russia has an extensive domestic distribution and export pipeline network. Russia's pipeline network is nearly completely owned and run by the state-run Transneft, which transports about 88% of all crude oil and about 27% of oil products produced in Russia. These pipelines include a number of domestic pipeline networks, pipelines that transport oil to export terminals such as Novorossiysk on the Black Sea and Primorsk on the Baltic Sea, as well as a number of export pipelines that deliver oil to western European markets. Russian export pipelines include Druzhba, Baltic Pipeline System, North-West Pipeline System, Tengiz-Novorossiysk, and Baku-Novorossiysk. All of these pipelines, with the exception of the Tengiz-Novorossiysk, are Transneft-controlled.

2.3.2 Colombia

Colombia produced 969,000 barrels per day (bbl/d) of oil in 2012, up 61% from the 604,000 bbl/d produced in 2008. EIA estimates that oil production in 2013 to be just over 1 million bbl/d and expects this rising trend to continue. The Ministry of Mines and Energy reported that Colombian production is expected to reach 1.3 million bbl/d by 2020. Colombia consumed 287,000 bbl/d in 2012, allowing the country to export most of its oil production.

Colombia's oil production has increased since 2008 because of increased exploration and development. New exploration and development were spurred by regulatory reform.

Figure 14 Colombia Map source: U.S. EIA

Much of Colombia's crude oil production occurs in the Andes foothills and the eastern Amazonian jungles. Meta department, in central Colombia, is also an important production area, predominately of heavy crude oil. Its Llanos basin contains the Rubiales oilfield, the largest producing oil field in the country.

The largest producing oil field in the country is the Rubiales heavy oil field, located in Meta department, and operated by partners Pacific Rubiales and Ecopetrol. Low levels of production began at Rubiales in the late 1980s, but increasing investment and the completion of a new pipeline have allowed production rates to rise in recent years. Gross production at Rubiales exceeded 177,000 bbl/d in 2012, up from 37,000 bbl/d in 2008. Other large oil fields include Cano Limon, Castilla, and Cupiagua.

Colombia has six major oil pipelines, four of which connect production fields to the Caribbean export terminal at Covenas. These include the 500-mile Ocensa pipeline, which has the capacity to transport 650,000 bbl/d from the Cusiana/Cupiagua area; the 460-mile, 220,000 bbl/d-capacity Cano Limon pipeline; and the smaller Alto Magdalena and Colombia Oil pipelines. The Llanos Orientales pipeline came online in late 2009, linking the Rubiales field to the Ocensa pipeline, with a capacity of 340,000 bbl/d. The sixth pipeline, the TransAndino, has a capacity of 190,000 bbl/d and transports crude from Colombia's Orito field in the Putumayo basin to Colombia's Pacific port at Tumaco linking to Ecuador.

Chapter 3

RESEARCH METHODOLOGY

3.1 Research Objective and Hypothesis

This research generates mixed-integer programming (MIP) baseline models and a proficient frontier curve, which include sampling plans for both pipeline quality and refinery sustainability performance, to evaluate the Quality and sustainability for Russia and Colombia. This research utilizes Microsoft Excel Solver to solve for optimal solutions. There are two primary research questions that we have to achieved in this section:

Research Objective 1: What is the impact of pipeline quality on crude oil supply chain efficiency?

Research Objective 2: What is the impact of sustainability on crude oil supply chain efficiency?

This paper evaluates weather or not the crude oil sustainability and pipeline quality impact the crude oil supply chain cost. To evaluate the impact, we introduce two set of hypothesis, which helps to answer the research question. In statistical hypothesis testing, two hypotheses are compared. These are called the null hypothesis and the alternative hypothesis. The null hypothesis is the hypothesis that states that there is no relation between the phenomena whose relation is under investigation, or at least not of the form given by the alternative hypothesis. The alternative hypothesis, as the name suggests, is the alternative to the null hypothesis: it states that there *is* some kind of relation. The alternative hypothesis may take several forms, depending on the nature of the hypothesized relation; in particular, it can be two-sided (for example: there is *some* effect, in a yet unknown direction) or one-sided (the direction of the hypothesized relation, positive or negative, is fixed in advance).

These two hypotheses statement are stated as follow:

Hypothesis Statement for Objective # 1

Null Hypothesis

H_0 : The crude oil pipeline quality will not impact the supply chain cost.

Alternative Hypothesis

H_1 : The crude oil pipeline quality will impact the supply chain cost.

Decision Rule

Reject H_0 if supply chain cost variation is greater than 15%.

Hypothesis Statement for Objective # 2

Null Hypothesis

H_0 : The environmental sustainability will not impact the supply chain cost.

Alternative Hypothesis

H_1 : The environmental sustainability will impact the supply chain cost.

Decision Rule

Reject H_0 if supply chain cost variation is greater than 15%.

3.2 Research Criteria and Approach

In this research, the distribution center (DC) model shown in Shapiro's book is utilized to show optimal locations to place distribution centers based on transportation distances and the size of the distribution centers. The model was worked in Microsoft Excel and used GRG nonlinear engine in Solver to solve the objective function. To achieve Research objective, we introduce three specific objective.

Specific Objective 1. Evaluate the supply chain factors that determine pipeline quality of crude oil production

Specific Objective 2. Evaluate the supply chain factors that determine Sustainability of crude oil production

Specific Objective 3. Evaluate the economic impacts of quality and sustainability on operational strategies in supplier network.

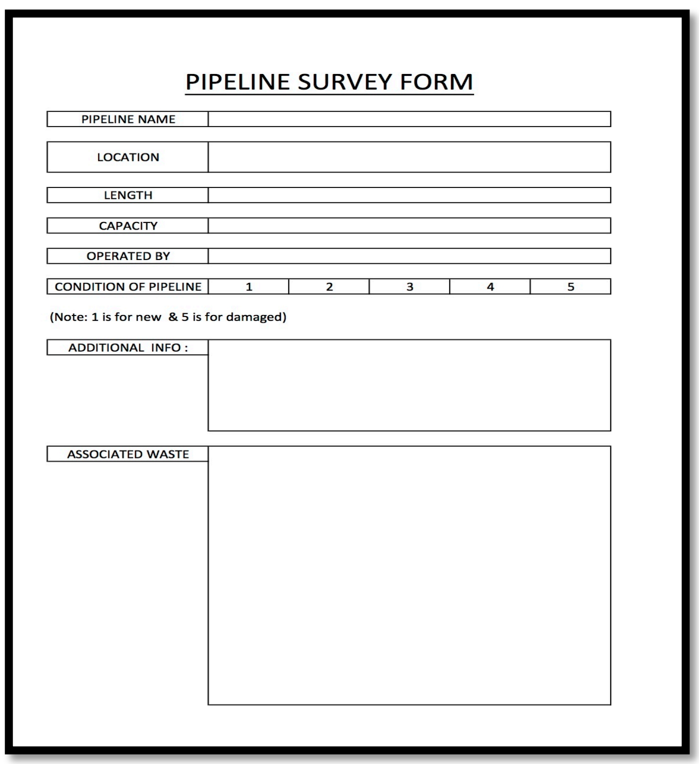
To satisfy the above three specific objective, we approach several steps.

3.2.1 Phase 1

In this phase we introduce steps to achieve Specific Objective 1. "Evaluate the supply chain factors that determine pipeline quality of crude oil production."

3.2.1.1 Step 1 - Questionnaire development

- Conduct a survey to observe different level of pipeline quality and loss associated with it.



PIPELINE SURVEY FORM

PIPELINE NAME					
LOCATION					
LENGTH					
CAPACITY					
OPERATED BY					
CONDITION OF PIPELINE	1	2	3	4	5

(Note: 1 is for new & 5 is for damaged)

ADDITIONAL INFO :

ASSOCIATED WASTE

Figure 15 Pipeline Survey Form

3.2.2.2 Step 2 – Evaluate the Performance Level for Quality

- From the survey, evaluate the level of Quality required to satisfy specific objective 1.

Following table show the performance level for pipeline quality

Table 3 Pipeline Quality Performance level

Quality Level	**Pipeline Quality Description**
1	Damaged and causing Non-Exempt Waste
2 (base)	Good Condition and causing little Non-Exempt Waste
3	New and Not Causing Non-Exempt waste

3.2.2 Phase 2

in this phase , we introduce steps to achieve Specific Objective 2. “Evaluate the supply chain factors that determine Sustainability of crude oil production.”

3.2.2.1 Step 3 – Questionnaire Development

- Conduct a detail study for all the refinery of Russia and Colombia to check its sustainability with respect to Process and Product.
- Following question need to be answered to get detailed report.
  1. What’s the energy consumption for process?
  2. Is the product environmental safe and non-hazardous?
  3. Do the company have any recycle process?
  4. Do they have any safety rules for employees?
  5. Usage of environment friendly material

3.2.2.2 Step 4 – Evaluate the performance level for Sustainability

With the help of detail study regarding refinery sustainability, we evaluate the following level of performance for refinery sustainability to satisfy specific objective 2.

Following table show the performance level for Refinery Sustainability.

Table 4 Refinery Sustainability Performance Level

Sustainability Level	**Refinery Sustainability Description**
1	High Energy Usage Consumption
2 (base)	Medium Energy Usage Consumption
3	Low Energy Usage Consumption

3.2.3 Phase 3

In this phase , we introduce steps to achieve Specific Objective 3. Evaluate the economic impacts of quality and sustainability on operational strategies in supplier network.

3.2.3.1 Step 5 – Selection of Oil field and Refinery

With the help of Quality and sustainability level, we choose following Oil field and refinery for Russia and Colombia.

For Russia and Colombia, we select only 2 oil field for each location. To extend the size, we introduce small and large oil field at all the location.

Table 5 Oil Field Numbering

I	Russia	Colombia
1	Samotlor- Large	Rubiales- Large
2	Samotlor- Small	Rubiales- Small
3	Preobskoye- Large	Cano Limon- Large
4	Preobskoye- Small	Cano Limon- Small

For refinery selection ,we select only some of the most important refinery. Russia and Colombia have so many refinery with wide range of choice.

Table 6 Refinery Numbering

j	Russia	Colombia
1	Angarsk	Barrancabermeja
2	Achinsk	Cartagena
3	Tuapse	Apiay
4	Syzran	Orito
5	Kuibyshev	Tibu
6	Novokuibyshevsk	-

3.2.3.2 Step 6 – Generate Scenario to Collect Data

According to oil fields location and performance level criteria, we have total 24 scenarios for Russia and Colombia. Each scenario represent the Data set for oil fields according to performance level of given selection criteria like pipeline quality or refinery sustainability.

Table 7 Scenarios Summary

Country	Oil Field Location	Sampling Plan	Performance Level	Scenario
Russia	Samotlor	Pipeline Quality	1	1
			2(base)	2
			3	3
		Refinery Sustainability	1	4
			2(base)	5
			3	6
	Preobskoye	Pipeline Quality	1	7
			2(base)	8
			3	9
		Refinery Sustainability	1	10
			2(base)	11
			3	12
Colombia	Rubiales	Pipeline Quality	1	13
			2(base)	14
			3	15
		Refinery Sustainability	1	16
			2(base)	17
			3	18

Table 7 -Continued

	Cano Limon	Pipeline Quality	1	19
			2(base)	20
			3	21
		Refinery Sustainability	1	22
			2(base)	23
			3	24

3.2.3.3 Step 7 – Model Generation

In this step, the distribution center (DC) model example printed in "Modeling the supply chain" textbook by Shapiro is used to show ideal locations for distribution centers which depends on transportation distances, associated transportation cost and the capacity of the distribution centers. The model was optimized in Microsoft Excel and used GRG nonlinear engine in Solver to maximize the objective function. The objective function was solved based on the oil transportation cost, the fixed costs for pipeline quality and refinery efficiency, and the variable costs for pipeline quality and refinery efficiency. Several scenarios were run that varied the transportation and variable costs in order to compare how pipeline quality and refinery sustainability impact the supply chain costs.

Objective Function

$$Max\ Z\colon \sum_{i\to 4} A_{ij}X_{ij}Y_{ij} + \sum_{i\to 4} B_{ij}Y_{ij} + \sum_{i\to 4} C_{ij}X_{ij}Y_{ij}$$

Where

A_{ij}= Transportation costs from field *i* to refinery *j*

B_{ij}= Fixed costs from field *i* to refinery *j*

C_{ij}= Sustainability costs from field *i* to refinery *j*

i = the oil field from where the oil originates

j = the refinery to where the oil is shipped and processed

X_{ij} = The number of barrels of oil shipped from field *i* to refinery *j*

Y_{ij} = The binary selection of moving oil from field *i* to refinery *j*

Constraints

1. Capacity Constraint

in the capacity constraint , No of barrels shipped from Oil field to Refinery must be less than Refinery capacity.

$$\sum_{i \to 4} X_{ij} \leq D_j$$

Where D_j is the capacity of Refinery *j*.

2. Selection Constraint

The selection of the refineries used at each location was constrained using a binary constraint. The fact that only one refinery would be used at each location, the sum of the two constraints needed to be less than or equal to 1 in order to work in Solver. These equations are

$$Y_{1j} + Y_{2j} \leq 1$$

$$Y_{3j} + Y_{4j} \leq 1$$

3.2.3.4 Step 8 – Data Collection

Crude oil supply chain quality data are collected from the Organization of the Petroleum Exporting Countries (OPEC) public databases, the U.S. Energy Information Administration (EIA) website, Russian Oil Company (Rosneft Corp), Russian oil transportation company (Transneft piping) and Colombian Oil Company (Ecopetrol). U.S. Energy Information Administration (EIA) and the U.S. Environmental Protection Agency (EPA) websites are used to collect data for sustainability.

Data set includes the oil transportation cost, distance, the fixed costs, and the variable costs.

3.2.3.5 Step 9 – Optimize the Model

The model was optimized in Microsoft Excel and used GRG nonlinear engine in Solver to maximize the objective function. Find total cost for all the 24 scenarios depend on Pipeline Quality and Sustainability.

Chapter 4

RESULTS

To get the optimum solution, we have to run the model with all 24 scenarios. Following are the results for each scenario. After getting the Result for all 24 scenario, we will do hypothesis testing to achieve research objective.

4.1 Scenario 1

Scenario 1 describe the pipeline quality level 1 for Samotlor oil field in Russia.

If Pipeline quality level is 1 (Damaged and Causing non-exempt waste), its transportation cost increases .

Table 8 Shows the Distance(km) and unit cost (ruble per hundred barrel) from Samotlor oil field to refineries.

Table 8 Transportation Distance and cost (Scenario 1)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.53	3.18	2.41	2.57	3.49	2.78
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 9 Shows the fixed cost and sustainability cost associated to Refinery for scenario 1.

Table 9 Fixed and Sustainability Cost (Scenario 1)

		Angarsk	Achinsk	Tuapse	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 9.11117E+11.

4.2 Scenario 2

Scenario 2 describe the pipeline quality level 2 for Samotlor oil field in Russia.

If Pipeline quality level is 2 (Good condition and Causing little non-exempt waste), its transportation cost remain standard . we considered this model as a base model.

Table 10 Shows the Distance(km) and unit cost (ruble per hundred barrel) from Samotlor oil field to refineries.

Table 10 Transportation distance and cost (Scenario 2)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.17	309	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 11 Shows the fixed cost and sustainability cost associated to Refinery for scenario 2.

Table 11 Fixed and Sustainability cost (Scenario 2)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 5.84768E+11.

4.3 Scenario 3

Scenario 3 describe the pipeline quality level 3 for Samotlor oil field in Russia.

If Pipeline quality level is 3 (New condition and not Causing non-exempt waste), its transportation cost remain lower than base model .

Table 12 Shows the Distance(km) and unit cost (ruble per hundred barrel) from Samotlor oil field to refineries.

Table 12 Transportation distance and cost (Scenario 3)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	1.73	2.38	1.61	1.77	2.69	1.98
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 13 Shows the fixed cost and sustainability cost associated to Refinery for scenario 3.

Table 13 Fixed and Sustainability cost (Scenario 3)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 7.84129E+11.

4.4 Scenario 4

Scenario 4 describe the Sustainability level 1 from Samotlor oil field in Russia.

If Refinery sustainability level is 1 (High Energy usage consumption), its sustainability cost increases .

Table 14 Shows the Distance(km) and unit cost (ruble per hundred barrel) from Samotlor oil field to refineries.

Table 14 Transportation Distance and cost (Scenario 4)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.14	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 15 Shows the fixed cost and sustainability cost associated to oil field for scenario 4.

Table 15 Fixed and Sustainability Cost (Scenario 4)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	159	131	148	139	122	119
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	133	119	139	127	117	114
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 8.3641E+11.

4.5 Scenario 5

Scenario 5 describe the Sustainability level 2 from Samotlor oil field in Russia.

If Refinery sustainability level is 2 (Medium Energy usage consumption), its sustainability cost remain normal . we considered this model as a base model.

Table 16 Shows the Distance(km) and unit cost (ruble per hundred barrel) from Samotlor oil field to refineries.

Table 16 Transportation Distance and cost (Scenario 5)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.14	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 17 Shows the fixed cost and sustainability cost associated to oil field for scenario 5.

Table 17 Fixed and Sustainability Cost (Scenario 5)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 5.84768E+11.

4.6 Scenario 6

Scenario 6 describe the Sustainability level 3 from Samotlor oil field in Russia.

If Refinery sustainability level is 3 (Low Energy usage consumption), its sustainability cost decreases .

Table 18 Shows the Distance(km) and unit cost (ruble per hundred barrel) from Samotlor oil field to refineries.

Table 18 Transportation Distance and cost (Scenario 6)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.14	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 19 Shows the fixed cost and sustainability cost associated to oil field for scenario 6.

Table 19 Fixed and Sustainability Cost (Scenario 6)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	119	91	108	99	82	79
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	93	79	99	87	77	74
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 8.29875E+11.

4.7 Scenario 7

Scenario 7 describe the pipeline quality level 1 for Preobskoye oil field in Russia.

If Pipeline quality level is 1 (Damaged and Causing non-exempt waste), its transportation cost increases .

Table 20 Shows the Distance(km) and unit cost (ruble per hundred barrel) from preobskoye oil field to refineries.

Table 20 Transportation Distance and cost (Scenario 7)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.17	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	3.09	4.52	2.36	2.81	5.09	2.88

Table 21 Shows the fixed cost and sustainability cost associated to Refinery for scenario 7.

Table 21 Fixed and Sustainability Cost (Scenario 7)

		Angarsk	Achinsk	Tuapse	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 9.17049E+11.

4.8 Scenario 8

Scenario 8 describe the pipeline quality level 2 for preobskoye oil field in Russia.

If Pipeline quality level is 2 (Good condition and Causing little non-exempt waste), its transportation cost remain standard . we considered this model as a base model.

Table 22 Shows the Distance(km) and unit cost (ruble per hundred barrel) from preobskoye oil field to refineries.

Table 22 Transportation distance and cost (Scenario 8)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.17	309	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 23 Shows the fixed cost and sustainability cost associated to Refinery for scenario 8.

Table 23 Fixed and Sustainability cost (Scenario 8)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 5.84768E+11.

4.9 Scenario 9

Scenario 9 describe the pipeline quality level 3 for Preobskoye oil field in Russia.

If Pipeline quality level is 3 (New condition and not Causing non-exempt waste), its transportation cost remain lower than base model .

Table 24 Shows the Distance(km) and unit cost (ruble per hundred barrel) from Preobskoye oil field to refineries.

Table 24 Transportation distance and cost (Scenario 9)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.17	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.29	3.72	1.56	2.01	4.29	2.08

Table 25 Shows the fixed cost and sustainability cost associated to Refinery for scenario 9.

Table 25 Fixed and Sustainability cost (Scenario 9)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 7.49348E+11.

4.10 Scenario 10

Scenario 10 describe the Sustainability level 1 from Preobskoye oil field in Russia.

If Refinery sustainability level is 1 (High Energy usage consumption), its sustainability cost increases .

Table 26 Shows the Distance(km) and unit cost (ruble per hundred barrel) from preobskoye oil field to refineries.

Table 26 Transportation Distance and cost (Scenario 10)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.14	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 27 Shows the fixed cost and sustainability cost associated to oil field for scenario 10.

Table 27 Fixed and Sustainability Cost (Scenario 10)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	147	122	141	147	131	118
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	123	115	131	134	112	115

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 8.36077E+11.

4.11 Scenario 11

Scenario 11 describe the Sustainability level 2 from preobskoye oil field in Russia.

If Refinery sustainability level is 2 (Medium Energy usage consumption), its sustainability cost remain normal . we considered this model as a base model.

Table 28 Shows the Distance(km) and unit cost (ruble per hundred barrel) from preobskoye oil field to refineries.

Table 28 Transportation Distance and cost (Scenario 11)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.14	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 29 Shows the fixed cost and sustainability cost associated to oil field for scenario 11.

Table 29 Fixed and Sustainability Cost (Scenario 11)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	127	102	121	127	111	98
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	103	95	111	114	92	95

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 5.84768E+11.

4.12 Scenario 12

Scenario 12 describe the Sustainability level 3 from preobskoye oil field in Russia.

If Refinery sustainability level is 3 (Low Energy usage consumption), its sustainability cost decreases .

Table 30 Shows the Distance(km) and unit cost (ruble per hundred barrel) from preobskoye oil field to refineries.

Table 30 Transportation Distance and cost (Scenario 12)

From/To		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor	Distance	1175	596	1916	1171	384	1127
	Cost	2.13	2.78	2.01	2.14	3.09	2.38
Priobskoye	Distance	876	312	2058	1382	178	1326
	Cost	2.69	4.12	1.96	2.41	4.69	2.48

Table 31 Shows the fixed cost and sustainability cost associated to oil field for scenario 12.

Table 31 Fixed and Sustainability Cost (Scenario 12)

		Angarsk	Achinsk	Tuaspe	Syzran	Kuibyshev	Novokuibyshevsk
Samotlor-Large	Fixed Cost	189000	123000	132000	151000	143000	149000
	Sustainability Cost	139	111	128	119	102	99
Samotlor-Small	Fixed Cost	129000	97000	101000	139000	136000	142000
	Sustainability Cost	113	99	119	107	97	94
Priobskoye- Large	Fixed Cost	176000	104000	128000	147000	141000	145000
	Sustainability Cost	107	82	101	107	91	78
Priobskoye-Small	Fixed Cost	103000	89000	99000	136000	133000	136000
	Sustainability Cost	83	75	91	94	72	75

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 8.30213E+11.

4.13 Scenario 13

Scenario 13 describe the pipeline quality level 1 for Rubiales oil field in Colombia.

If Pipeline quality level is 1 (Damaged and Causing non-exempt waste), its transportation cost increases .

Table 32 Shows the Distance(km) and unit cost (peso per barrel) from Rubiales oil field to refineries.

Table 32 Transportation Distance and cost (Scenario 13)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.32	2.65	4.95	2.76	2.91
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 33 Shows the fixed cost and sustainability cost associated to Refinery for scenario 13.

Table 33 Fixed and Sustainability Cost (Scenario 13)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.6274E+8.

4.14 Scenario 14

Scenario 14 describe the pipeline quality level 2 for Rubiales oil field in Colombia.

If Pipeline quality level is 2 (Good condition and Causing little non-exempt waste), its transportation cost remain standard . we considered this model as a base model.

Table 34 Shows the Distance(km) and unit cost (peso per barrel) from Rubiales oil field to refineries.

Table 34 Transportation Distance and cost (Scenario 14)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 35 Shows the fixed cost and sustainability cost associated to Refinery for scenario 14.

Table 35 Fixed and Sustainability Cost (Scenario 14)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4201E+8.

4.15 Scenario 15

Scenario 15 describe the pipeline quality level 3 for Rubiales oil field in Colombia.

If Pipeline quality level is 3 (New condition and not Causing non-exempt waste), its transportation cost remain lower than base model .

Table 36 Shows the Distance(km) and unit cost (peso per barrel) from Rubiales oil field to refineries.

Table 36 Transportation Distance and cost (Scenario 15)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	2.99	2.21	4.53	2.46	2.63
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 37 Shows the fixed cost and sustainability cost associated to Refinery for scenario 15.

Table 37 Fixed and Sustainability Cost (Scenario 15)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.2398E+8.

4.16 Scenario 16

Scenario 16 describe the Sustainability level 1 from Rubiales oil field in Colombia.

If Refinery sustainability level is 1 (High Energy usage consumption), its sustainability cost increases .

Table 38 Shows the Distance(km) and unit cost (peso per barrel) from Rubiales oil field to refineries.

Table 38 Transportation Distance and cost (Scenario 16)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 39 Shows the fixed cost and sustainability cost associated to Refinery for scenario 16.

Table 39 Fixed and Sustainability Cost (Scenario 16)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	145	131	105	113	117
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	139	124	96	101	104
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4796E+8.

4.17 Scenario 17

Scenario 17 describe the Sustainability level 2 from Rubiales oil field in Colombia.

If Refinery sustainability level is 2 (Medium Energy usage consumption), its sustainability cost remain normal . we considered this model as a base model.

Table 40 Shows the Distance(km) and unit cost (peso per barrel) from Rubiales oil field to refineries.

Table 40 Transportation Distance and cost (Scenario 17)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 41 Shows the fixed cost and sustainability cost associated to Refinery for scenario 17.

Table 41 Fixed and Sustainability Cost (Scenario 17)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4201E+8.

4.18 Scenario 18

Scenario 18 describe the Sustainability level 3 from Rubiales oil field in Colombia.

If Refinery sustainability level is 3 (Low Energy usage consumption), its sustainability cost decreases .

Table 42 Shows the Distance(km) and unit cost (peso per barrel) from Rubiales oil field to refineries.

Table 42 Transportation Distance and cost (Scenario 18)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 43 Shows the fixed cost and sustainability cost associated to Refinery for scenario 18.

Table 43 Fixed and Sustainability Cost (Scenario 18)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	119	107	86	97	101
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	109	101	78	89	93
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.3942E+8.

4.19 Scenario 19

Scenario 19 describe the pipeline quality level 1 for Cano limon oil field in Colombia.

If Pipeline quality level is 1 (Damaged and Causing non-exempt waste), its transportation cost increases .

Table 44 Shows the Distance(km) and unit cost (peso per barrel) from Cano limon oil field to refineries.

Table 44 Transportation Distance and cost (Scenario 19)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.31	2.11	3.46	2.43	2.59

Table 45 Shows the fixed cost and sustainability cost associated to Refinery for scenario 19.

Table 45 Fixed and Sustainability Cost (Scenario 19)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4213E+8.

4.20 Scenario 20

Scenario 20 describe the pipeline quality level 2 for cano limon oil field in Colombia.

If Pipeline quality level is 2 (Good condition and Causing little non-exempt waste), its transportation cost remain standard . we considered this model as a base model.

Table 46 Shows the Distance(km) and unit cost (peso per barrel) from cano limon oil field to refineries.

Table 46 Transportation Distance and cost (Scenario 20)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 47 Shows the fixed cost and sustainability cost associated to Refinery for scenario 20.

Table 47 Fixed and Sustainability Cost (Scenario 20)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4201E+8.

4.21 Scenario 21

Scenario 21 describe the pipeline quality level 3 for cano limon oil field in Colombia.

If Pipeline quality level is 3 (New condition and not Causing non-exempt waste), its transportation cost remain lower than base model .

Table 48 Shows the Distance(km) and unit cost (peso per barrel) from cano limon oil field to refineries.

Table 48 Transportation Distance and cost (Scenario 21)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	1.98	1.75	3.02	1.99	2.27

Table 49 Shows the fixed cost and sustainability cost associated to Refinery for scenario 21.

Table 49 Fixed and Sustainability Cost (Scenario 21)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4190E+8.

4.22 Scenario 22

Scenario 22 describe the Sustainability level 1 from Cano Limon oil field in Colombia.

If Refinery sustainability level is 1 (High Energy usage consumption), its sustainability cost increases .

Table 50 Shows the Distance(km) and unit cost (peso per barrel) from Cano limon oil field to refineries.

Table 50 Transportation Distance and cost (Scenario 22)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 51 Shows the fixed cost and sustainability cost associated to Refinery for scenario 22.

Table 51 Fixed and Sustainability Cost (Scenario 22)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	151	144	98	112	119
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	146	135	91	101	105

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4204E+8.

4.23 Scenario 23

Scenario 23 describe the Sustainability level 2 from Cano limon oil field in Colombia.

If Refinery sustainability level is 2 (Medium Energy usage consumption), its sustainability cost remain normal . we considered this model as a base model.

Table 52 Shows the Distance(km) and unit cost (peso per barrel) from Cano limon oil field to refineries.

Table 52 Transportation Distance and cost (Scenario 23)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 53 Shows the fixed cost and sustainability cost associated to Refinery for scenario 23.

Table 53 Fixed and Sustainability Cost (Scenario 23)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainability Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	138	125	86	98	102
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	124	119	79	95	92

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4201E+8.

4.24 Scenario 24

Scenario 24 describe the Sustainability level 3 from Cano Limon oil field in Colombia.

If Refinery sustainability level is 3 (Low Energy usage consumption), its sustainability cost decreases .

Table 54 Shows the Distance(km) and unit cost (peso per barrel) from Cano limon oil field to refineries.

Table 54 Transportation Distance and cost (Scenario 24)

From/To		barrancabermeja	Cartagena	Apjay	Orito	Tibu
Rubiales	Distance	248	507	86	380	335
	Cost	3.14	2.42	4.78	2.59	2.79
Cano Limon	Distance	300	556	98	315	401
	Cost	2.12	1.94	3.28	2.14	2.43

Table 55 Shows the fixed cost and sustainability cost associated to Refinery for scenario 24.

Table 55 Fixed and Sustainability Cost (Scenario 24)

		barrancabermeja	Crtagena	Apjay	Orito	Tibu
Rubiales-Large	Fixed Cost	183000	188000	149000	120000	131000
	Sustainabilit Cost	127	114	91	101	106
Rubiales-Small	Fixed Cost	178000	185000	143000	114000	129000
	Sustainability Cost	113	109	88	97	97
Cano limon-Large	Fixed Cost	165000	173000	143000	116000	129000
	Sustainability Cost	131	119	82	91	95
Cano Limon-Small	Fixed Cost	158000	166000	136000	111000	125000
	Sustainability Cost	119	107	69	82	83

Run the scenario with Excel using GRG nonlinear , we obtain the total value is 3.4200E+8.

4.25 Efficiency Curve

The optimum solution for all the 24 scenarios provide enough information for 8 efficiency curve .

Table 56 shows total value for Samotlor oil field in Russia for sceanrio 1,2,3 according to pipeline quality level.

Table 56 Samotlor-Pipeline quality

Scenario	Quality Level	Total Cost
1	1	9.11117 E+11
2	2 (base)	5.84768 E+11
3	3	7.84129 E+11

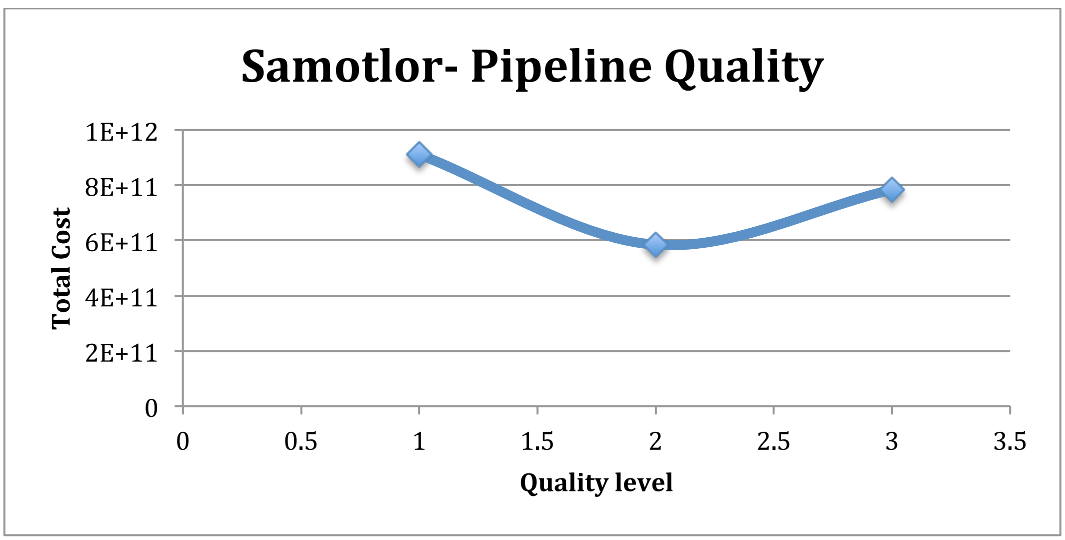


Figure 16 Samotlor- Russia Frontier Curve (Pipeline Quality)

From the above efficiency curve we can say that change the pipeline quality can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other 2 quality level increase the total cost by more than 30% for Samotlor oil field.

Table 57 shows total value for Samotlor oil field in Russia for sceanrio 4,5,6 according to Refinery Sustainability level.

Table 57 Samotlor- Refinery Sustainability

Scenario	Sustainability Level	Total Cost
4	1	8.3641 E+11
5	2 (base)	5.84768 E+11
6	3	8.29875 E+11

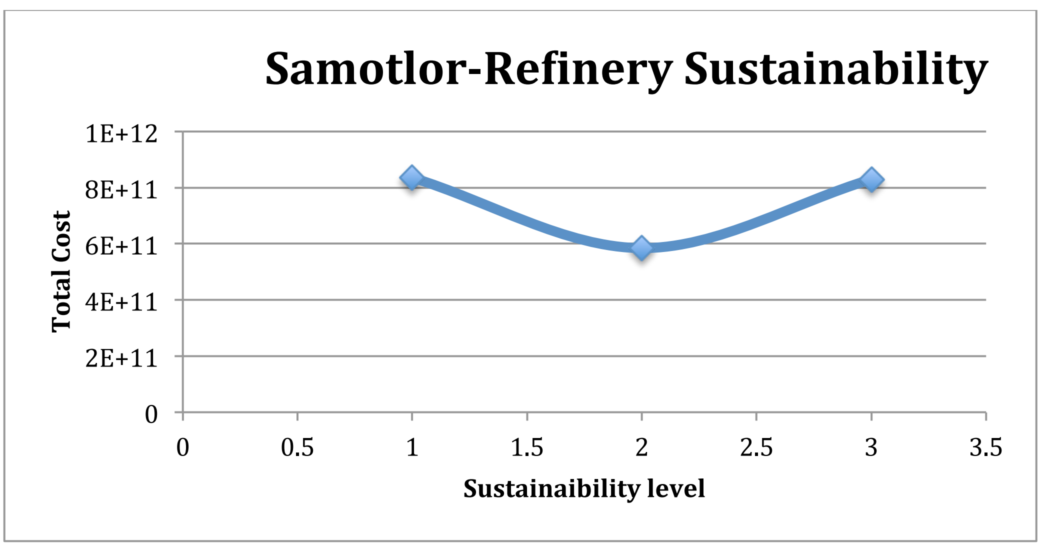


Figure 17 Samotlor- Russia Frontier Curve (Refinery Sustainability)

From the above efficiency curve we can say that change the sustainability can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other 2 level increase the total cost by nearly 33% for Samotlor oil field.

Table 58 shows total value for Preobskoye oil field in Russia for sceanrio 7,8,9 according to pipeline quality level.

Table 58 Preobskoye-Pipeline quality

Scenario	Quality Level	Total Cost
7	1	9.17049 E+11
8	2 (base)	5.84768 E+11
9	3	7.49348 E+11

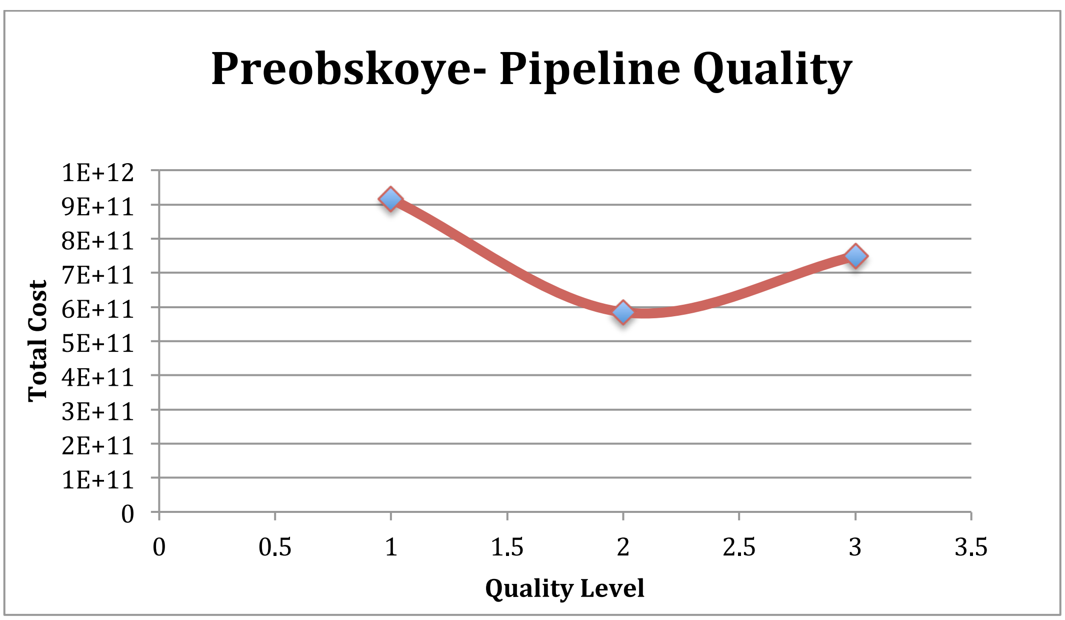


Figure 18 Preobskoye- Russia Frontier Curve (Pipeline Quality)

From the above efficiency curve we can say that change the pipeline quality can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other 2 quality level increase the total cost by more than 25%.

Table 59 shows total value for Preobskoye oil field in Russia for sceanrio 10,11,12 according to Refinery Sustainability level.

Table 59 Preobskoye - Refinery Sustainability

Scenario	Sustainability Level	Total Cost
10	1	8.36077 E+11
11	2 (base)	5.84768 E+11
12	3	8.30213 E+11

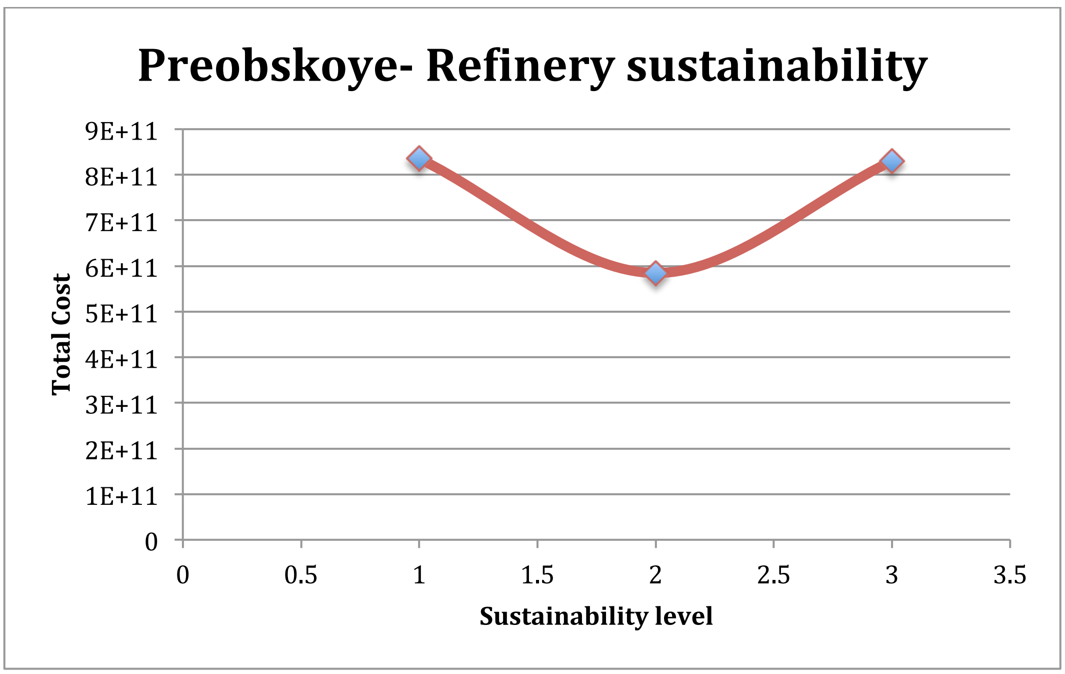


Figure 19 Preobskoye- Russia Frontier Curve (Refinery Sustainability)

From the above efficiency curve we can say that change the sustainability can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other 2 level increase the total cost by more than 33%

Table 60 shows total value for Rubiales oil field in Colombia for sceanrio 13,14,15 according to Pipeline quality level.

Table 60 Rubiales - Pipeline Quality

Scenario	Quality Level	Total Cost
13	1	3.6274 E+8
14	2 (base)	3.4201 E+8
15	3	3.2398 E+8

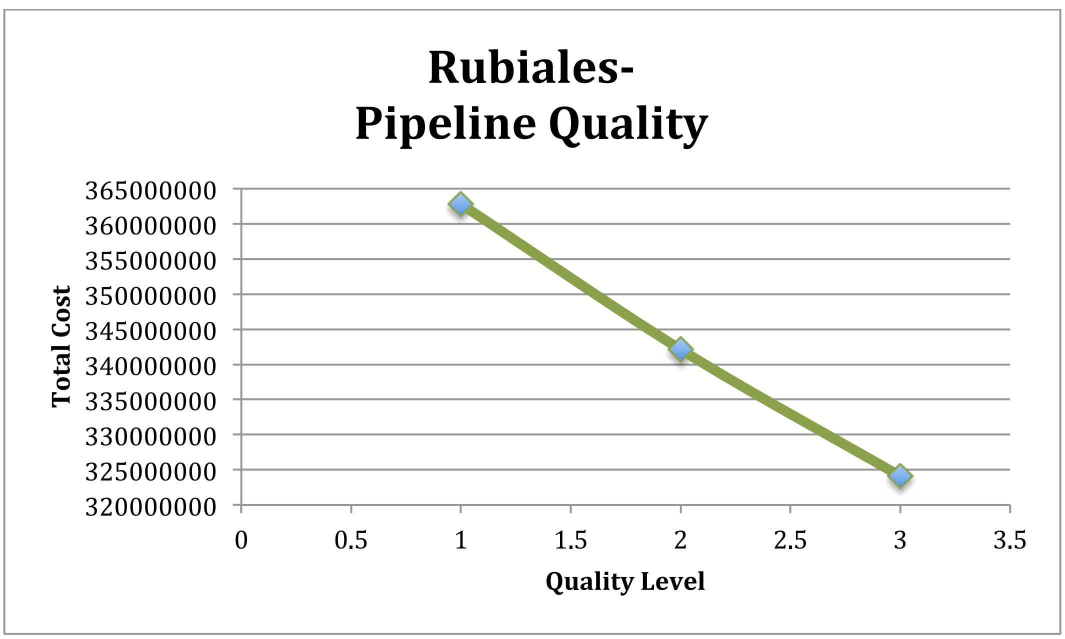


Figure 20 Rubiales- Colombia Frontier Curve (Pipeline Quality)

From the above efficiency curve we can say that change the pipeline quality can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other lower quality level increase the total cost and higher quality level reduce the total cost. Total cost variation with respect to base model is nearly 6%

Table 61 shows total value for Rubiales oil field in Colombia for sceanrio 16,17,18 according to Refinery Sustainability level.

Table 61 Rubiales- Refinery Sustainability

Scenario	Sustainability Level	Total Cost
16	1	3. 4796 E+8
17	2 (base)	3.4201 E+8
18	3	3.3942 E+8

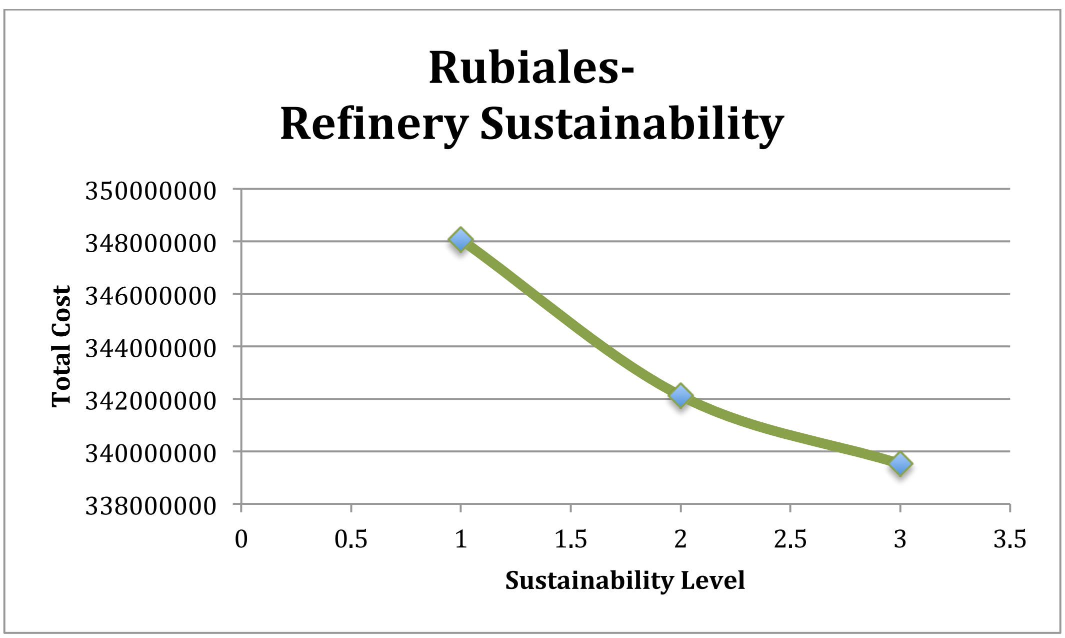


Figure 21 Rubiales- Colombia Frontier Curve (Refinery Sustainability)

From the above efficiency curve we can say that change the sustainability can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other lower quality level increase the total cost and higher quality level reduce the total cost. Total cost variation with respect to base model is nearly 2%.

Table 62 shows total value for Cano Limon oil field in Colombia for sceanrio 19,20,21 according to Pipeline Quality level.

Table 62 Cano Limon - Pipeline quality

Scenario	Quality Level	Total Cost
19	1	3.4212 E+8
20	2 (base)	3.4201 E+8
21	3	3.4190 E+8

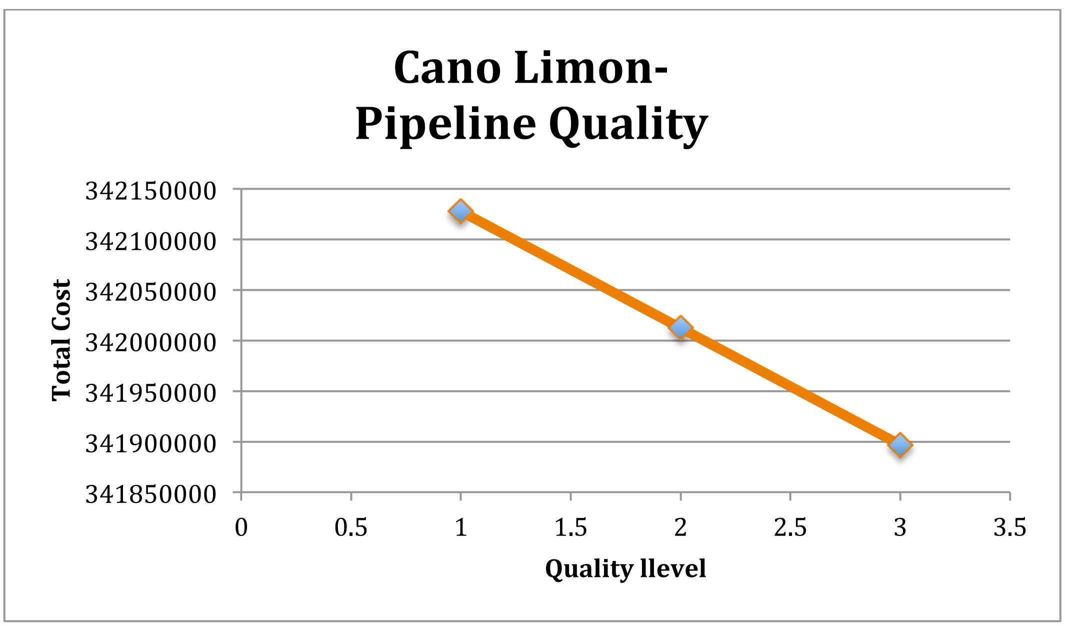


Figure 22 Cano-limon Colombia Frontier Curve (Pipeline Quality)

From the above efficiency curve we can say that change the pipeline quality can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other lower quality level increase the total cost and higher quality level reduce the total cost. Total cost variation with respect to base model is nearly 4%.

Table 63 shows total value for Cano Limon oil field in Colombia for sceanrio 22,23,24 according to Refinery Sustainability level.

Table 63 Cano Limon - Refinery Sustainability

Scenario	Sustainability Level	Total Cost
22	1	3.4204 E+8
23	2 (base)	3.4201 E+8
24	3	3.4199 E+8

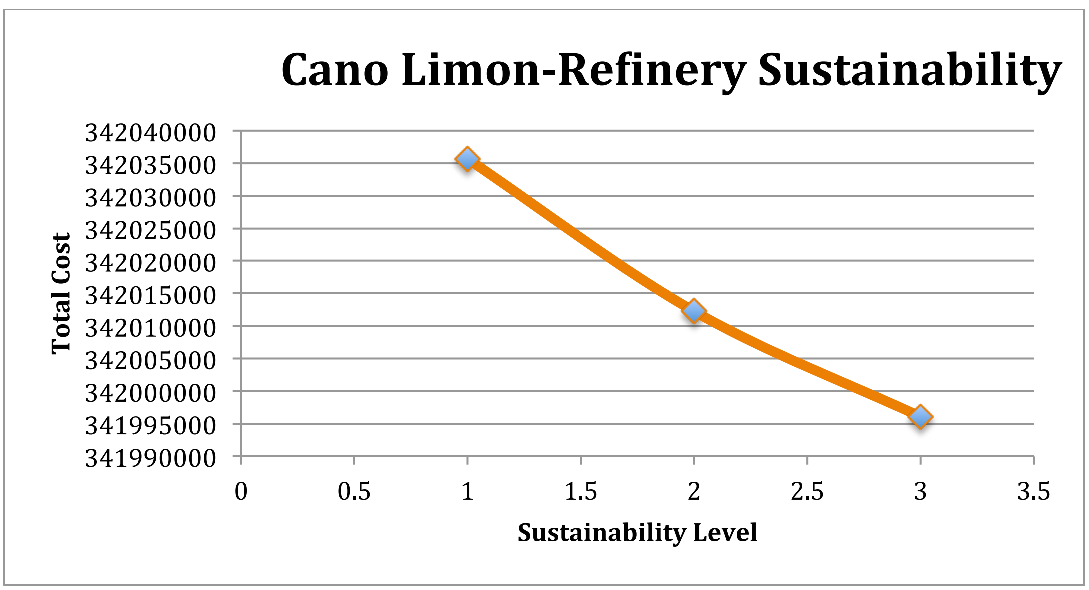


Figure 23 Cano-limon Colombia Frontier Curve (Refinery Sustainability)

From the above efficiency curve we can say that change the sustainability can affect the total cost. The pattern of the curve showing that the base model has optimal total cost while other lower quality level increase the total cost and higher quality level reduce the total cost. Total cost variation with respect to base model is nearly 1%.

From the above efficiency curve, we have to find cost variation for each case and perform hypothesis testing. In order to reject each hypothesis , the model needed to show that both the pipeline quality and refinery sustainability changed the total supply chain cost by 15%.

Chapter 5

CONTRIBUTION TO THE BODY OF KNOWLEDGE

5.1 Conclusion

There are three expected results from this research.

1) We expected to reject our H_0 with respect to predefined hypothesis that the crude oil supply chain quality and sustainability impact crude oil supply chain costs.
2) We expected the crude oil supply chain quality level to impact the supply chain cost model by more than 15 percent.
3) We expected the crude oil supply chain sustainability factor to impact the supply chain cost model by more than 15 percent.

Following table shows cost variation by percentage for Russia and Colombia with respect to pipeline quality and refinery sustainability level.

Table 64 Cost Variation by Percentage

	Russia		Colombia	
	Samotlor	Priobskoye	Rubiales	Cano Limon
Pipeline Quality	34%	28%	6%	4%
Refinery Sustainability	42%	42%	2%	1%

For Russia, cost variation is more than 15% in both the cases, so we have to reject null hypothesis. In other world, Pipeline Quality and refinery sustainability will impact the supply chain cost.

For Colombia, cost variation is less than 15% in both the cases, so we fail to reject null hypothesis. In other world, Pipeline Quality and refinery sustainability will not impact the supply chain cost.

From the above result , we can say that it's a good chance for USA to invest in Colombia for future imports.

5.2 Limitation

There are some expected limitations for this research such as the availability of data and scope of the research. The U.S. EIA provides copious amounts of useful data for the U.S. oil industry. There are certain limitations for the data collection of the Russia and Colombian oil industry due to lack of information.

5.3 Future Work

The importance of the proposed research is a comparison of pipeline quality and environmental sustainability on supply chain cost for Russia and Colombia. The broader impacts of the proposed research are how investments into other countries' crude oil supply chains can be quantified and optimized; and exporting countries such as Russia and Colombia can be considered as possible candidates for investment for future global needs.

The scope of this research is to extend the research for Indonesia Oil Supply chain and use the methodology for Russia and Colombia. This scope is already broad enough considering the nature of supply chain activities on both countries. Future work can be conducted as the continuation of this research, which uses the proposed model that includes other countries and add more variables as type of oil transportation and some other add on value factors.

Appendix A

US Petroleum and other liquids Production, Estimated Consumption and Net imports

From 1995-2013

U.S. Petroleum and Other liquids Production, Estimated Consumption and Net imports from 1995-2013 (million Barrels per day)

Year	Production	Estimated Consumption	Net imports
1995	9.39989315	17.72458904	8.32469589
1996	9.44454918	18.3089071	8.86435792
1997	9.46093973	18.62030411	9.15936438
1998	9.27800548	18.91714521	9.63913973
1999	8.9934137	19.51933973	10.52592603
2000	9.05777596	19.70107923	10.64330327
2001	8.95700822	19.64870685	10.69169863
2002	8.99843288	19.76130685	10.76287397
2003	8.76583288	20.03350685	11.26767397
2004	8.72242077	20.73115574	12.00873497
2005	8.32468767	20.80215616	12.47746849
2006	8.31616438	20.68741918	12.3712548
2007	8.46932055	20.68038082	12.21106027
2008	8.56359563	19.49796721	10.93437158
2009	9.13379726	18.77139726	9.6376
2010	9.68453151	19.18012877	9.49559726
2011	10.13620821	18.88207397	8.74586576
2012	11.11735507	18.49021585	7.37286078
2013	12.31197483	18.88679944	6.57482461

Preliminary Data U.S. EIA October 2014, web

Appendix B

U.S. Net imports of crude oil and petroleum products from Saudi Arabia, Canada, Russia

And Colombia (2004-2014)

U.S. Net imports of Crude oil and Petroleum products from Saudi Arabia, Canada, Russia and Colombia from 2004-2014 (Thousand Barrels)

Year	Net Imports	Saudi Arabia	Canada	Russia	Colombia
2004	12097	1557	1980	298	173
2005	12549	1536	2001	410	188
2006	12390	1462	2194	368	149
2007	12036	1483	2266	413	148
2008	11114	1529	2229	464	181
2009	9667	1003	2257	562	240
2010	9441	1096	2302	612	300
2011	8450	1193	2377	624	371
2012	7393	1364	2530	477	358
2013	6237	1326	2593	460	273
2014	5041	1162	2586	327	174

Preliminary Data U.S. EIA October 2014, web

Appendix C

Russia Crude Oil Production, Consumption and Net exports (1992-2013)

Russia Crude Oil Production, Consumption and Net Exports from 1992-2013 (thousand barrels per day)

Year	Crude Oil Production	Consumption	Estimated Net Export
1992	7631.929	4423.1588	3395.5581
1993	6730	3750.4598	3200.5467
1994	6135	3178.9824	3127.8767
1995	5995	2976.1331	3196.3559
1996	5850	2619.4548	3397.1023
1997	5920	2562.4824	3538.608
1998	5854	2488.6083	3581.0568
1999	6078.948	2537.6239	3774.6924
2000	6479.202	2578.4981	4145.1408
2001	6917	2590.2318	4569.503
2002	7408.173	2636.4088	5022.4824
2003	8132.1988	2681.8629	5852.9157
2004	8804.7077	2750.8139	6522.9565
2005	9043.0822	2785.1365	6726.1051
2006	9247.2055	2803.4681	6928.8821
2007	9437.0634	2885.101	7053.0811
2008	9356.7836	2981.919	6893.1139
2009	9495.3649	2888.534	7161.0184
2010	9694.1145	3134.8999	7158.9405
2011	9773.5178	3352.108	7057.955
2012	9921.6093	3395.109	7199.6916
2013	10053.8438	3515.143	7248.5994

Source: U.S. Energy Information Administration

Appendix D

Colombia Crude Oil Production, consumption and Net Exports (1990-2013)

Colombia Crude Oil Production, Consumption and Net Exports 1990-2013 (thousand barrels per day)

Year	Crude Oil Production	Consumption	Estimated Net Export
1990	440	208.9058	245.0924
1991	419	209.8785	219.8971
1992	433	232.5302	212.2805
1993	456	240.2192	227.1003
1994	450	244.4073	218.0097
1995	585	250.6331	346.421
1996	622.9645	278.1295	363.924
1997	652	286.5139	378.8357
1998	732.518	289.02	456.9996
1999	816	282	548.194
2000	690.5765	277.4874	426.6286
2001	625	271.1817	365.6424
2002	576.9397	256.1985	332.0776
2003	540.733	265.3557	289.3206
2004	528.7613	267.5158	274.4406
2005	525.7931	270.7081	269.9784
2006	531.0385	276.9701	271.3819
2007	531.1352	270.1889	275.9195
2008	588.3567	265.2192	338.4548
2009	670.6457	259.6515	430.6252
2010	785.5262	269.883	536.0068
2011	914.2544	294.2727	644.2705
2012	944.2186	304	665.0549
2013	1003.2463	306	722.4737

Source: U.S. Energy Information Administration

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