Evaluating the Impact of Sustainability and Pipeline Quality on Global Crude Oil Supply Chain Efficiency

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***Abstract*—In this paper, the efficiency Curve model shown in "M*odelling the Supply Chain" (Author: Shapiro)* is modified to compare Crude oil supply chain among Indonesia, Russia and Columbiabased on oil transportation distances and associated cost, refinery costs, and the costs associated with refinery sustainability and pipeline quality. However this model was originally used to determine the optimal locations of distribution centres based on transportation cost and the capacity of the distribution centres, this model was modified to allow the use of different costs associated with the quality condition of the pipeline and the costs of sustaining an environmentally friendly facility. This case used to optimize the total cost of oil supply chain for Indonesia, Russia and Columbia. We seek to extend our previous supply chain model, which represent the outbound oil supply chain. 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 Indonesia, Russia and Columbia.**

***Keywords*— *supply chain management, efficiency curve, quality, sustainability, optimization, crude oil supply chain, Russian Oil pipeline, and Oil refinery.*

1. Introduction

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 relied on net imports (imports minus exports) for about 33% of the petroleum (crude oil and petroleum products) that we consumed in 2013. Just over half of these imports came from the Western Hemisphere. Our dependence on foreign petroleum has declined since peaking in2005.The current U.S. sources for oil is not limited to politically stable countries but it relies heavily 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.

Oil dependency is a long-term threat. The rising cost of oil dependence affects all aspects of American society and threatens national security. If the U.S. wishes to reduce these threats in the future, the U.S. must properly fund energy research and development to commercialize technologies that will break America's oil dependency.

1.1 Dependency

North America is the largest consumer of oil regionally, followed by Asia (primarily Japan), Europe, and then other world regions. Though, the U.S. is a top producer of crude oil, its current rate of petroleum consumption is between 18 and 19 million barrels of oil per day, and its domestic

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production cannot handle the demand, hence its reliance on imported oil is necessary. However, according to the United States Energy Information Administration (U.S. EIA), the net imported oil of the U.S. has declined since peaking in 2005 – see Figure 1 [33]

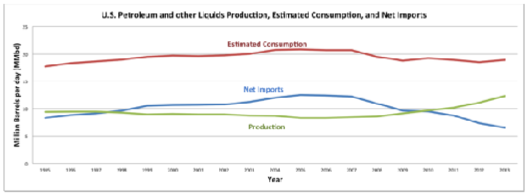

Figure 1. U.S. Petroleum and Other Liquids Production, Estimated Consumption, and Net Imports from 2000 – 2013. Preliminary Data: U.S. EIA, October 14, 2014.

The U.S. EIA stated that theU.S. consumed an estimated 18.88 million barrels per day (MMbd) of petroleum products and produced 12.31MMbd of crude oil and petroleum products during 2013[33]. 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 [33]. 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 [33]. 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 [33]. This is problematic due to the fact 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.

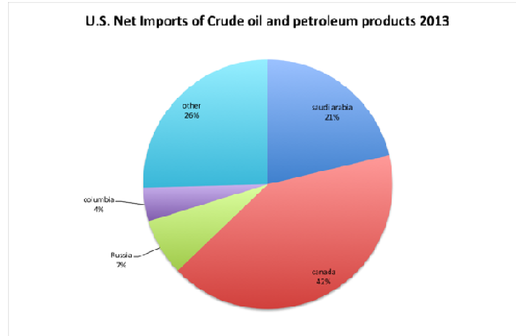

Figure 2. U.S. Net Imports of Crude Oil and Petroleum Products from Saudi Arabia, Canada, Russia and Columbia in 2013. Preliminary Data: U.S. EIA, October 14, 2014.

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 Indonesia 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 Indonesia 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, specifically in Indonesia so that it becomes more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources.

The remainder of this paper is organized as follows: Section II provides background of the problem; Section III organizes the components and discusses the methodology of the model; Section IV discusses the results from the model; and Section V concludes the paper and addresses some of the limitations of the research.

2. Background

Each day, the United States uses millions of gallons of crude oil to support our daily lives. While many forms of transportation are used to move this product to storage hubs and refineries, pipelines remain the safest, most efficient and economical way to move this natural resource [29].

Bjorklund explained important characteristics to consider in the design of environmental performance measurements in supply chain management[3].Platts suggested that measuring the total actual acquisition costs is useful to gain profitability in supply chain networks[14].Additionally, this research follows a similar methodology as Billy that provided a set of scenarios, which affect the total supply chain cost [1].The specific model that was derived for the use this paper is the Distribution Center model from Shapiro's modeling the Supply Chain [22].
Sources of crude oil pipeline failure include 40%, structural problems,6% operator error, 25%other, 27% outside force damage and lastly, 2% control problems Agbaeze [44].

There are three quality metrics that are considered for pipeline performance. The first metric is the failure of a pipeline segment. This involves a complete loss of a particular segment of a pipeline to transport crude oil. Possible causes include unplanned maintenance, accidental excavation damage, or sabotage. The second metric is the loss of the crude oil transmission compressor. This focuses on partial reductions in deliverability due to removal from service of one or more crude oil compressors. Possible causes include forced outage of a compressor driver, an explosion or fire in the compressor station, or the failure of ancillary systems. The third metric is the loss of deliverability from storage facilities. This includes the loss of deliverability from one or more of the major underground storage fields.

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"[27].

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.

Moffat and Linden compiled background research and information that is associated with oil pipeline failures. It shows that for crude oil pipelines, the causes of failures appeared to be fairly random in nature, and that no trends were apparent [46].

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" [25].

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. An industrial plant that refines crude oil into petroleum products such as diesel, gasoline and heating oils. 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 vary on the petroleum products demand.

There are two sustainability metrics that are considered for refineries performance. The first metric is the refining operations, which deal with energy usage necessary for operating refineries, emissions, and waste. The second metric 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.

3. Methodology

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. 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.

This chapter evaluates whether or not the crude oil supply chain quality and the environment sustainability will impact the supply chain costs for Russia and Colombia.

To compare the supply chain cost for both place, we have to generate a standard model, which we use for both locations of Russia and Colombia.

These two hypothesis statement are stated as follow:

Hypothesis Statement #1

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

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

Hypothesis Statement #2

H_0: The environment sustainability will not impact the crude oil supply chain costs.

H_1: The environment sustainability will impact the crude oil supply chain costs.

The rejection region for$H_0$is verified or rejected for both of the hypothesis statements if both supply chain quality and environment sustainability metrics change the supply chain costs by more than fifteen percent.

In this research, the distribution center (DC) model example printed in "Modeling the supply chain" textbook by Shapiro is used to show ideal locations for distribution centers whichdepends 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. These factors are identified in Table 1 and Table 2.

Table 1. Pipelines Quality Level Performance

Quality Level	Pipeline Quality Description
1	Damaged and Causing Non-Exempt Wastes
2 (Base)	Damaged and Not Causing Non-Exempt Wastes
3	New and Not Causing Non-Exempt Wastes

Table 2. Refinery Sustainability Level Performance

Sustainability Level	Refinery Sustainability Description
4	High Energy Usage Consumption
5 (Base)	Medium Energy Usage Consumption
6	Low Energy Usage Consumption

For the objective function, Eq. (1) was derived:

$$Max: \sum_{i\to 4} A_{ij}X_{ij}Y_{ij} + \sum_{i\to 4} B_{ij}Y_{ij} + \sum_{i\to 4} C_{ij}X_{ij}Y_{ij} \quad (1)$$

Where:

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

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

C_{ij}= Variable 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*

Table 3 and Table 4 identify the *i* and *j* values for each of the oil fields and refineries in Russia and Colombia

Table 3. Oil Field Numbering

i	Oil Field	
	Russia	**Colombia**
1	Samotlor-large	Rubiales -large
2	Samotlor-small	Rubiales-small
3	Preobskoye-large	Cano Limon -large
4	Preobskoye-small	Cano Limon - small

Table 4. Refinery Numbering

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

The following equations were used as constraints to ensure that capacities of the pipelines were met:

$$\sum_{i\to 4} X_{ij} \geq D_{ij} \quad (2)$$

Where D_{ij} is the pipeline capacity for the pipeline from field *i* to refinery *j*

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 shown in Eq. (3) and Eq. (4).

$$Y_{1j} + Y_{2j} \leq 1 \quad (3)$$

$$Y_{3j} + Y_{4j} \leq 1 \quad (4)$$

A snapshot of the excel base model for Russia and Colombia is shown in figure 3,4 and 5,6 respectively. This model allows the user to enter transportation cost and variable cost depending upon the pipeline quality and sustainability level you choose.

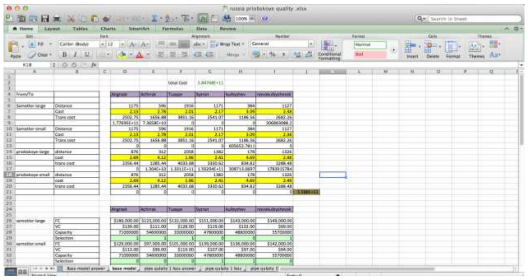

Figure 3. Snapshot of Russia base model -1

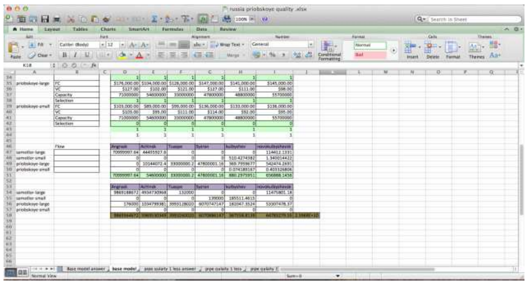

Figure 4. Snapshot of Russia base model -2

For Russia (figure 3 &figure 4), The objective function contains transportation cost in J21, small refinery cost in J55&J57, and large refinery cost in J54&J56. There only should be one facility at each location, so we introduced a binary variable for facility selection which is shown in excel from D29:I29, D33:I33,D38:I38,D42:I42. The total cost is shown in G2.

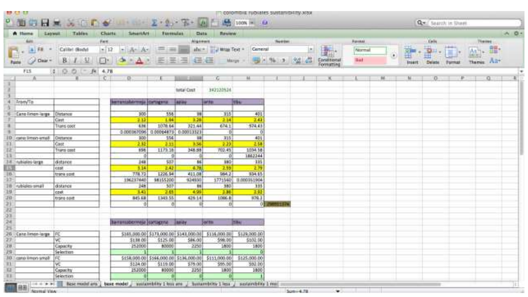

Figure 5. Snapshot of Colombia base model-1

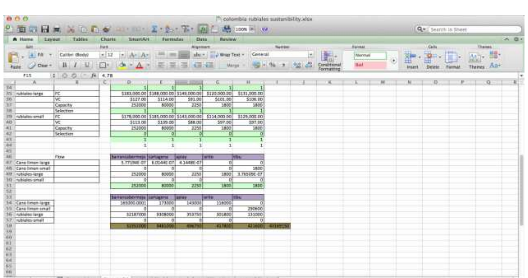

Figure6. – Snapshot of Colombia base model -2

For Colombia (figure 5 &figure 6), the objective function contains transportation cost in I21, small refinery cost in I55&I57, and large refinery cost in I54&I56. There only should be one facility at each location so we introduced binary variable for facility selection which shown in excel from D29:H29, D33:H33,D38:H38,D42:H42. The total cost is shown in G2.

4. Expected Results

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 levelto 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.

The optimum solution is for Russia and Columbia is given below with respect to quality level and sustainability level.

Table 5. Total Cost with respect to quality level for Russia

Russia		
Quality	**Samotlor**	**Preobskoye**
Level 1	9.11117E+11	9.17049E+11
Level 2	5.84768E+11	5.84768E+11
Level 3	7.84129E+11	7.49348E+11

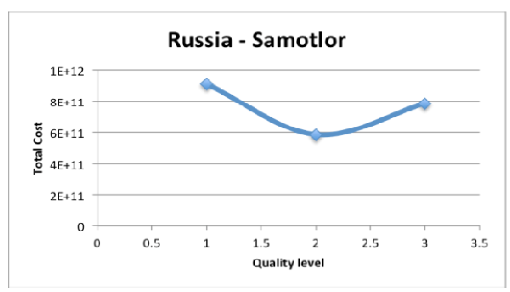

Figure 7. Samotlor Oil Fields Pipeline Quality

Table 6. Total Cost with respect to sustainability

level for Russia

Russia		
Sustainability	**Samotlor**	**Preobskoye**
Level 1	8.3641E+11	8.36077E+11
Level 2	5.84768E+11	5.84768E+11
Level 3	8.29875E+11	8.30213E+11

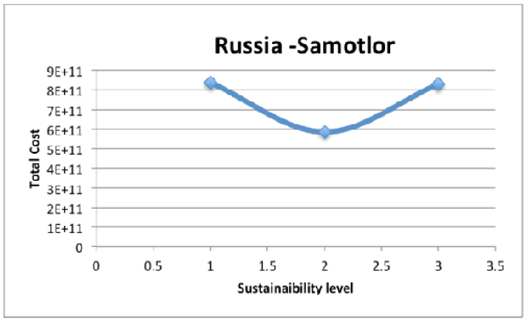

Figure 8. Samotlor Oil Fields Refinery Sustainability

Figure 9. Preobskoye Oil Fields Pipeline Quality

Figure 10. Preobskoye Oil Fields Refinery Sustainability

In order to reject each hypothesis, the model needed to show that both the pipeline quality and refinery sustainability changed the supply chain costs by 15%.

For Russia, Both the Quality and Sustainability affect the total cost by more than 15%. So according to hypothesis test, we reject the null hypothesis.

So in statement: “The crude oil supply chain quality and the environmental sustainability will impact the supply chain cost.”

Table 7. Total Cost with respect to quality level for Colombia

Colombia		
Quality	**Cano Limon**	**Rubiales**
Level 1	342199922	362847779
Level 2	342120524	342120524
Level 3	341997818	324091229

Table 8. Total Cost with respect to sustainability level for Colombia

Colombia		
Sustainability	**Cano Limon**	**Rubiales**
Level 1	342143924	348069624
Level 2	342120524	342120524
Level 3	342104324	339526074

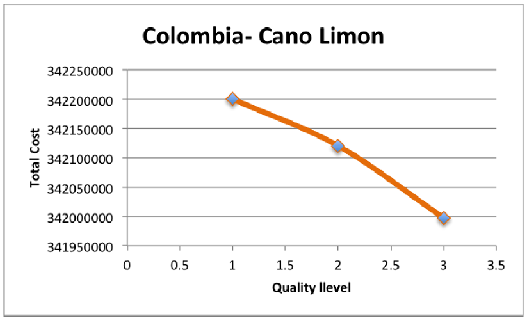

Figure 11. Cano Limon Oil Fields Pipeline Quality

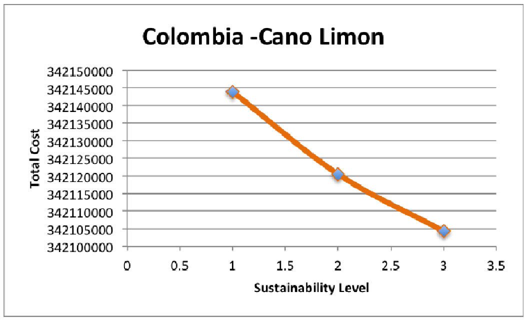

Figure 12. Cano Limon Oil Fields Refinery Sustainability

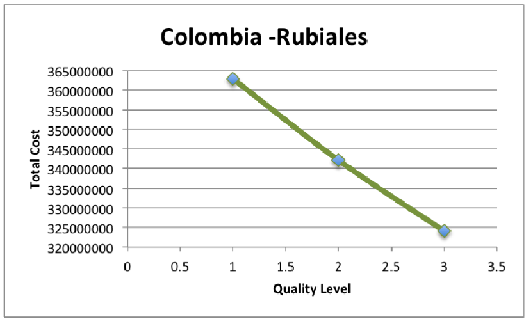

Figure 13. Rubiales Oil Fields Pipeline Quality

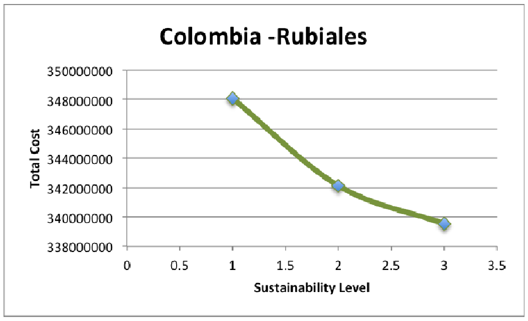

Figure 14. Rubiales Oil Fields Refinery Sustainability

In order to reject each hypothesis, the model needed to show that both the pipeline quality and refinery sustainability changed the supply chain costs by 15%.

For Colombia, Both the Quality and Sustainability affect the total cost by way less than 15%. So according to the hypothesis test, we fail to reject the null hypothesis.

So in statement: "The crude oil supply chain quality and the environmental sustainability will not impact the supply chain cost."

The following table shows the percentage impact of Quality and sustainability on total cost.

		Pipeline Quality	Environmental Sustainability
Indonesia	Duri	5%	3%
	Minas	6%	3%
Russia	Samotlor	34%	42%
	Preobskoye	28%	42%
Colombia	Cano Limon	4%	1%
	Rubiales	6%	2%

5. Limitations and Broader Impacts

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 Indonesian oil industry due to lack of information. 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.

The importance of the proposed research is a comparison of pipeline quality and environmental sustainability on supply chain cost for Indonesia, 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.

6. Conclusion

This research raises important questions about crude oil supply chain and effectiveness of oil quality and environment sustainability on Supply chain cost. As a result of conducting a research, I observed the effect on supply chain cost for 3 locations around the world. In Russia, Quality and sustainability has more effect on cost than Indonesia and Colombia.

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