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**Brunel Business School**

MG 5510 Dissertation

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MSc in Global Supply Chain Management

***Agility Enablers in the Upstream O&G Industry in response to crude oil price fluctuation: Application to Peru***

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## **Abstract**

This research aims to define the agility enablers in situations of crude oil price fluctuation in a petroleum industry. It is analysed through a case study applied in Peruvian northwest sector, where a combination of mathematical models that are influenced by the crude oil price are simulated for a ten-year projection. The outcomes of the simulation are numerical metrics as Operating Income for each simulation scenario proposed. These metrics are classified under linguistic labelling in order to search with them the agility enablers previously applied or suggested in investigations, papers, journal, report, etc. in similar situations. After correlating the agility enablers found with the calculated parameter in each simulation scenario, the findings and conclusions show twenty-one enablers found and applied in nine main operations for five scenarios of crude oil price behaviour, showing a combination of options for applying these enablers in cases of high or low price over the years.

*Keywords: Agility Enablers, Upstream Sector, Crude Oil Price, Petroleum Company, Production and Development Process, Oil and Gas Industry.*

[Total number of words: 11,943 from Introduction to the reference section (excluding)]

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# 1. Introduction

## 1.1. Research Background

The fluctuation of crude oil price is a fact that has affected the world economy in the last ten years, changing from 100 US\$/bbl to 64 US\$/bbl. This variation reached a daily volatility of 19% between 2014 and 2016, being four times higher than the levels from 2010 to 2014 (Olinto et al., 2018). In addition, the biggest price drop in history was presented at the beginning of 2016, when the price per barrel fell up to \$ 29 (Macrotrends, 2019; OPEC, 2018).

Historically, crude oil prices have been high since oil and gas companies have not had a real need to establish a culture of cost optimisation. For example, when the barrel of crude oil price exceeded \$100 between 2006 and 2013, the expenditure in production per barrel was doubled from \$4 to \$7.6. In this period, the petroleum companies had a clear incentive to invest in technical solutions that would allow them to produce more (Olinto et al., 2018).

However, with the current environment of low prices and the constant volatility status, this has meant a cut of expenditures in exploration and production, varying according to the region, company and type of asset, decreasing investments in drilling activities and new projects. Similarly, the operating companies stopped their expenses, reducing costs and seeking to increase the efficiency in their operations (Nassif, 2017; OPEC, 2018).

This need to efficiently manage the internal operations leads to process improvement and cost optimisation in order to sustain the company's profitability margins for any oil price variation scenario. Therefore, achieving the agility that is needed by the companies of the sector now. (Anyadike, 2017; Del-Maestro and Stevens, 2017; Olinto et al., 2018).

According to Garbie and Al-Hosni (2014), the agility concept in petroleum companies is considered as a new evaluation, and it is still an ill-structured problem. The creation of an agile system in this industry represents a fundamental change in the management of both internal and related operations with the oilfield service companies (Anyadike, 2017; Del-Maestro and Stevens, 2017; Gunasekaran et al., 2002). These enablers are not small-scale improvements, but they must be applied over the time to achieve a different way of doing business, with a primary emphasis on flexibility and a quick response to the changing market (Garbie and Al-Hosni, 2014; Gunasekaran et al., 2002).



## **1.2. Research problem, question and aim**

As it is indicated in the Research Background, the crude oil price fluctuation internally affects the strategic and production decisions in an oil and gas company; which impacts over the production cost finally.

In order to mitigate the economic impact of the fluctuation uncertainty, some studies such as: Garbie (2011), Garbie and Al-Hosni (2014), Menhat and Yusuf (2018), Olinto et al. (2018), Yusuf et al. (2014), Yusuf, Musa et al. (2014), among others, propose the agility concept as a method of business optimisation and supply chain performance in this sector. Thus, a more flexible industry can face the continuous changes in prices and market uncertainty (Agarwal et al., 2016; Dillinger, 2019).

These studies are focused on improving quickness, flexibility, responsiveness, quality and profitability, in this industry as well as in any other. However, from the literature review, it is observed that some agility enablers are more suitable to be applied in cases of high or low crude oil price. In consequence, in order to predict and respond to the uncertainty mentioned above, the study will answer the following main question: What are the agility enablers to be applied in different scenarios of crude oil price variation for the coming years?

For that, a petroleum company in Peru is analysed as a case study, seeking to develop the following steps:

- Step 1. Define the possible future scenarios of crude oil price fluctuation in the next 10 years and their impact in the Total Production Cost, Revenue and in each operative functions of the company.
- Step 2: Calculate the Profit Margin Ratios and assign a qualitative classification to the ratios and to the crude oil price behaviour.
- Step 3: Based on the literature review, compare and define the cases when the agility enablers were applied, considering the qualitative labelling defined in Step 2.
- Step 4: Analyse and suggest the agility enablers to each scenario of crude oil price.

## **1.3. Dissertation Outline**

The dissertation is outlined as follows: introduction, literature review, research methodology, methods and data collection, analysis and results, findings and conclusion.

The introduction includes the study background, where the worldwide current situation about crude oil price fluctuation will be summarised and it will be explained how the operating companies respond to these changes. Also, there will be an explanation about how the agility concept is included in the sector as performance strategy of those operating companies, leading to define the aim of the research related to the definition of agility enablers to be applied in different scenarios of price variation for the coming years.

After that, the literature review will be developed to explain the petroleum industry in Peru, the production process and the crude oil price fluctuation in the last years. Moreover, the agility concept is detailed in the sector; as well as, its enablers applied in different previous studies.

In the section 3, there will be an explanation about how the methodology was used in the investigation, in which the study design will be summarized in two analysis stages. After that, the Simulation Model will be explained in the section 4 where the data collection will be detailed as well as the input and output variables. In addition, the mathematical models and calculations will be described, and the linguistic analysis model will be explained to be used in the quantitative and qualitative stage, respectively. This process is shown in Figure 1, where the variables are further explained in the section 4.

In the sections 5 and 6, the data will be analysed, and the variables and models will be calculated, showing the results of the study and interpreting the findings. Finally, conclusions will be stated in section 7.

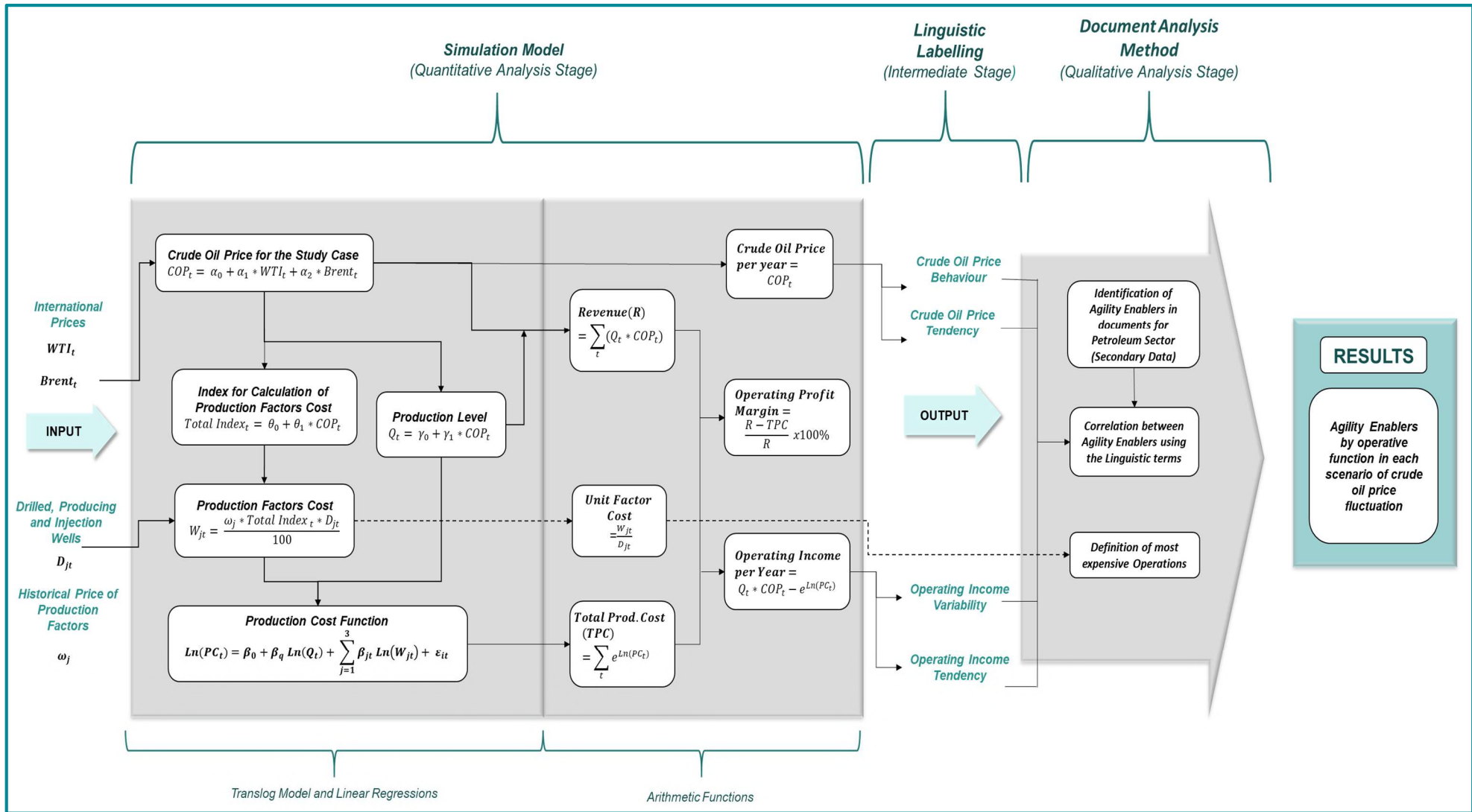


Figure 1: Application process of Case Study: Quantitative and Qualitative Analysis

## 2. Literature Review

### 2.1. Overview of Oil & Gas Industry

The Oil and Gas (O&G) industry is one of the world's largest and most important global industries where the oil meet for one-third of the world's energy needs, and both the oil and gas accounts for more than half of the global energy demand (Chowdhury, 2016; Inkpen and Moffett, 2011).

The demand of this energy resource has grown steadily in the recent years due to the accelerated expansion of productive activities, industrialisation, transportation, migration processes from the countryside to the city and the urbanisation in developing economies (Chowdhury, 2016; Tamayo *et al.*, 2015). Subsequently, this sector has placed greater emphasis in recent years on the execution of investment projects for the exploration and development of new O&G reserves; as well as, in the development of unconventional reserves - shale oil (Penas and González, 2018; Tamayo *et al.*, 2015).

In order to understand what the industry is about, the Figure 2 shows the O&G value chain (Tamayo *et al.*, 2015), integrated by three main segments: upstream, midstream and downstream. The first segment activities include exploration, development and production; the second segment includes activities of trading and transporting of crude oil and natural gas. At last, the third segment includes the refining, storage and marketing (Inkpen and Moffett, 2011).

In any value chain, inputs and outputs are deterministic, as it is indicated by Chowdhury (2016), that is, with a given input (investment), one is assured of the planned output (product or services). Nevertheless, the input is deterministic while the output is stochastic in the O&G industry, which implies that both the result of the exploration and the production are high risk and uncertain, since in case of obtaining a productive field, the upstream would become more profitable than the downstream. Conversely, if no reserves are found in the field, it would imply a loss for the company (Inkpen and Moffett, 2011).

In the same way, the activities in the Upstream industry include the use of high technology activity that implies a high operating cost because of the application of science (geology, geophysics, mathematic) and engineering (petroleum, chemical, reservoir, instrumentation, telecommunication) including others (Chowdhury, 2016). Therefore, the study of the Upstream sector is needed since the activities of exploration and production are becoming increasingly costly, risky and technology-intensive (Chowdhury, 2016).

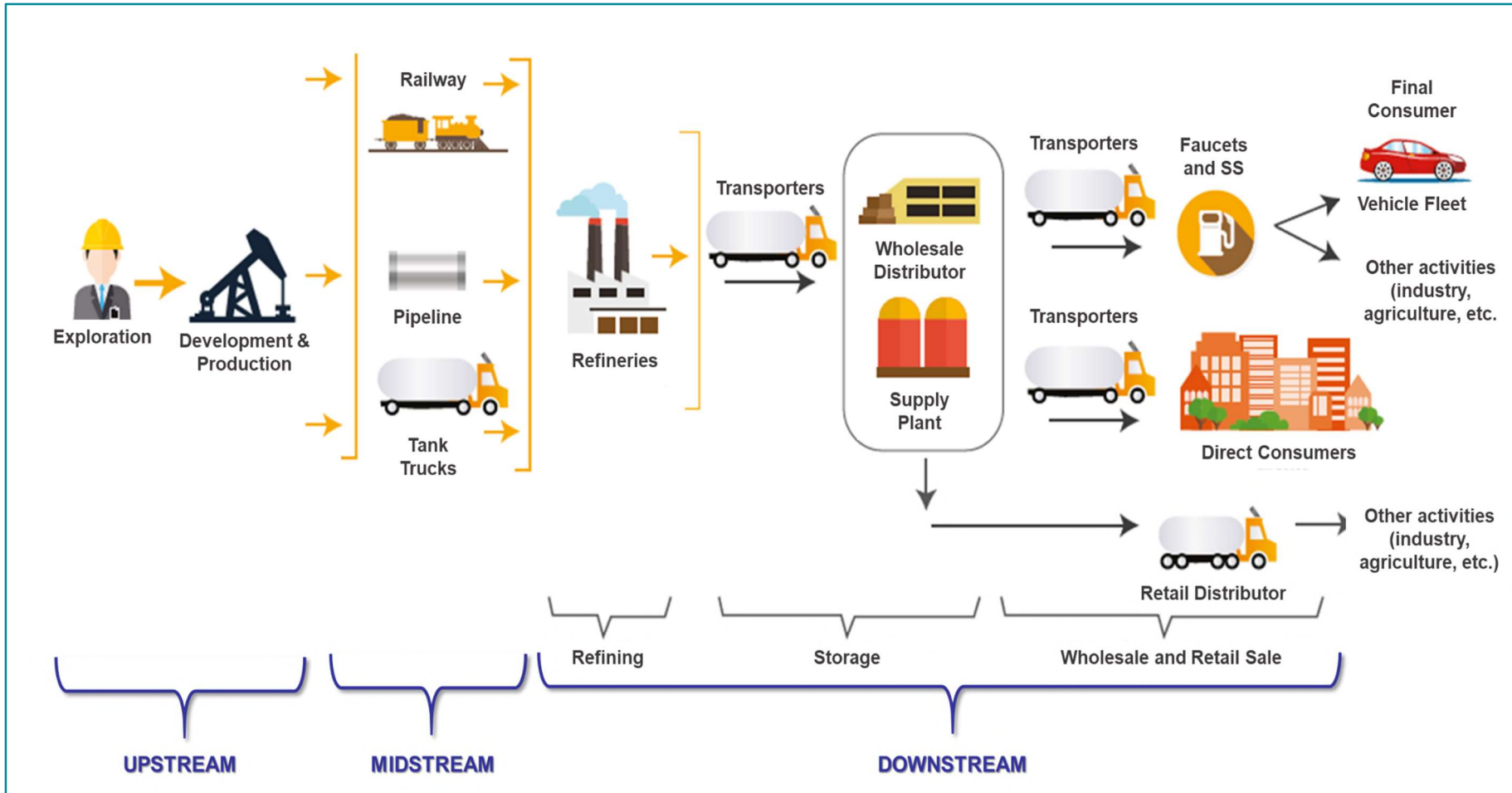


Figure 2: Oil and Gas Value Chain (Adapted from: Tamayo *et al.*, 2015)

## **2.2. Petroleum Sector in Peru**

The petroleum development and production began in Peru since 1863 with the drilling of the first well in Tumbes city. This fact was also the beginning of the petroleum industry in Latin America (De-La-Vega *et al.*, 2018; Osinerg, 2005). Since then, Peru is seen as an attractive investment destination due to its stable economy and legal stability since the 1990's, which economy has grown by 141% between 2000 and 2018 (BCRPData, 2019; De-La-Vega *et al.*, 2018). Last year, the foreign investment amounted to 21,708 million dollars, increasing by 1.5% in respect to 2017 (Osinergmin, 2019; Iparraguirre, 2018).

Peru seeks to increase the foreign investment in the hydrocarbon sector, especially in the upstream sector, not only due to its significant impact on the Peruvian economy but also to increase the amount of local production processed in Peruvians refineries. This premise responds to the current low level of national production, which quantity only fulfil the 22% of the Peruvian refineries' capacity. For this reason, Peru must import crude oil from Ecuador, Brazil, Colombia and other countries, which is processed in the 55% of the Peruvian refineries' capacity, leaving an unused capacity of 23%. (Osinergmin, 2018; Osinergmin, 2019; PERUPETRO, 2019; Tamayo *et al.*, 2015).

Also, Seferino Yesquén, the PERUPETRO's president indicates that the great challenges of Peru in the upstream sector are to maximise the production of the current fields and to widen the exploration horizon (De-La-Vega *et al.*, 2018).

Furthermore, considering the current international context, crude oil prices have still slumped more than 60% of their value compared to 2014. Certainly, this puts companies at a stage, in which, it will be necessary to produce more. Thus, Peru is focused on projects development which guarantee the production increase through the wells' recovery and the optimisation of production and development phases (De-La-Vega *et al.*, 2018).

## **2.3. Crude Oil Price Fluctuation in the Last Decade**

The O&G industry, as many other sectors, is affected by potential threats and opportunities of its macro-environment (Elsaghier, 2017; Pitt and Koufopoulos, 2012). One of the most determining external factors for the business performance of a hydrocarbon company is the crude oil price fluctuation due to the high level of uncertainty and complexity that this factor creates in the industry (Agarwal *et al.*, 2016; Dillinger, 2019; Pitt and Koufopoulos, 2012).

The world market has focused its attention on three international markers that serve as an indicator for setting the price of other crude oils: WTI<sup>1</sup>, Brent<sup>2</sup> and Dubai<sup>3</sup>, where the OPEC oil prices lead the first two markers and have a dominant role in global crude oil markets (Tamayo *et al.*, 2015; Zhang, Ji and Kutan, 2019).

Such markers have fluctuated in the last 10 years, as it is shown in Figure 3 (Jobert *et al.*, 2019; Macrotrends, 2019), where a fall was presented between 2013 and 2015, having as one of the main causes the excess of supply from shale oil in the USA and the OPEC decision to not reduce its production quota. This decision was made to maintain its market share in the face of the threat of new sources of unconventional supply (Macrotrends, 2019; Tamayo *et al.*, 2015). At the end of 2016, OPEC countries members and other countries committed to cut their production, which together with the Venezuela economic fall, contributed to the projection of lower OPEC production. In consequence, an increase in the price occurred afterwards. (Krauss and Reed, 2016; LasAmericas, 2017).

It is important to understand the behaviour of the international market since it determines the profitability of production projects, affecting the performance of the upstream sector of 'price-taking' countries like Peru (Arroyo and Cossío, 2015; Tamayo *et al.*, 2015).

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<sup>1</sup> West Texas Intermediate, US market reference (New York Mercantile Exchange)

<sup>2</sup> European market reference (The International Petroleum Exchange)

<sup>3</sup> Asian market reference (The Singapore International Monetary Exchange)

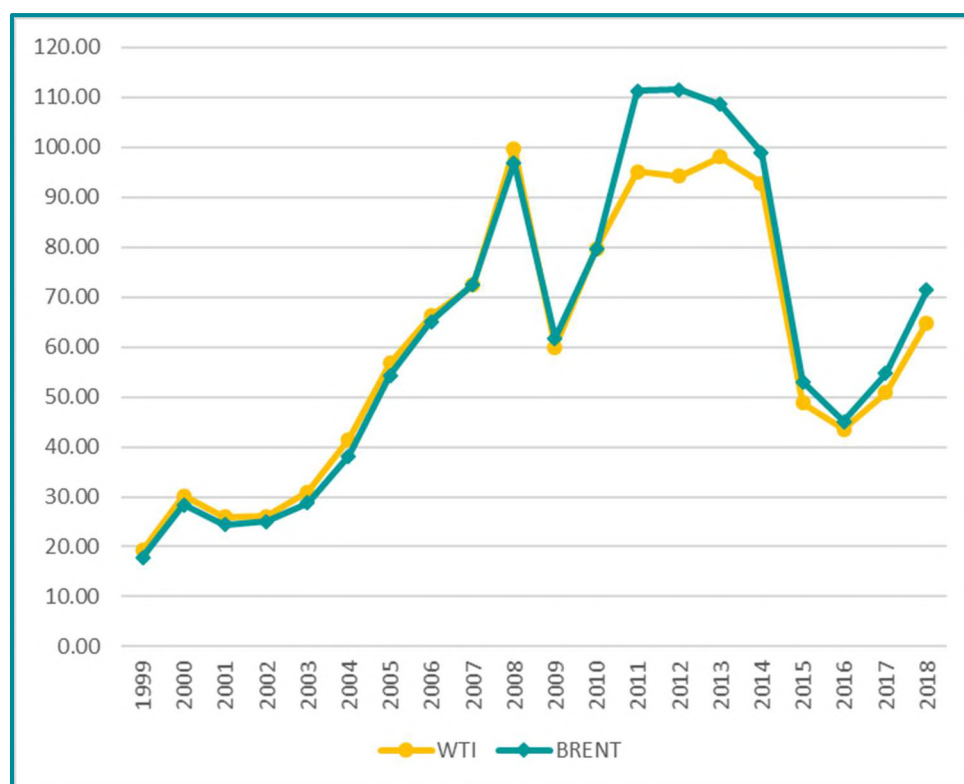


Figure 3 – Crude Oil Price fluctuation for 20 years of WTI and Brent (*Macrotrends, 2019*)

## 2.4. Impact of Crude Oil Price Fluctuation in Peruvian Petroleum Sector

This fluctuation creates uncertainty about the company profitability in the exploration projects, development projects and the investment decisions of petroleum producing companies (Elsaghier, 2017).

Laughton (1998) and Favero et al. (1992) assure that the investment decision delayed by the producing companies and their relationship with crude oil price uncertainty are directly correlated. So that, the producing companies have greater difficulty in making the investment decision when the price is more volatile. This behaviour varies depending on the regions of operation and its economic activity. For example, North America shows a reversed U shaped curve, Asia shows U shaped curve and Europe shows a positively correlated linear shape (Henriques and Sadorsky, 2011; Zhu and Singh, 2016).

In Peru, La-Rosa (2018) determines, through the use of a regression econometric model, the existence of positive correlations between the international prices and its investment impact in exploration, development and production of crude oil in Peru. On the whole, this has a direct effect on production decisions (Kilian, 2009). For example, the Figure 4 shows a comparison between 2018 regarding to 2013, where a decrease



of 35% of the price represents a decrease by 22% in the production level in BPD<sup>4</sup> (PERUPETRO, 2019).

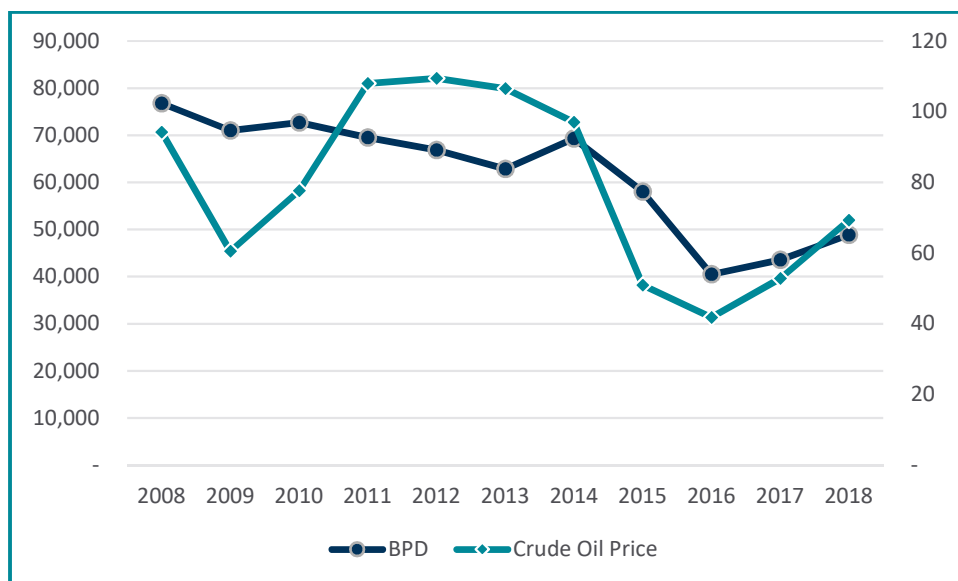


Figure 4: Crude Oil Price and Production Level (PERUPETRO, 2019).

Bearing in mind that Peru is a main producer, an importer of crude oil (Osinermin, 2018) and also considering the fall in the price in the last five years (Macrotrends, 2019), the producing companies have been affected by the increase in production costs (Daicz and Monlezún, 2016).

These companies are forced to maintain the wells production which are already working because of the high fixed cost that the oil activity involves in the exploration and drilling stage, despite that the price level is insufficient to recover the initial investment. Thus, petroleum companies are currently implementing cost reductions to continue with the production or reducing the numbers of new drilled wells (Daicz and Monlezún, 2016; De-La-Vega *et al.*, 2018; PERUPETRO, 2019).

## 2.5. Petroleum Extraction Process

According to the US Environmental Protection Agency (2000), the process of the oil extractive industry in the Upstream of the sector, can be classified into four main stages: exploration, well development, production and field abandonment. As it is illustrated, Figure 5 shows the operative or productive functions in summary, as well as the materials and equipment needed at each stage of the petroleum extraction process.

<sup>4</sup> Barrels Per Day

The exploration involves the evaluation of rock formations associated with O&G deposits, also includes geophysical prospecting and exploratory well drilling. The geological evaluation of these deposits allows to determine if it is recommendable to exploit the deposit by drilling wells (US EPA, 2000; Ego and Orihuela, 2014).

Once an economically recoverable field has been located, the drilling begins in the development stage through the construction of one or more additional wells, confirming the discovery of hydrocarbons and installing the facilities for its production. In case this stage is not productive, the abandonment of the field occurs.

The production is the process of extracting hydrocarbons from the subsoil and separating the mixture of liquids, gases and solids, in order to sell O&G. After the production of oil from the field, the area is abandoned with the removal of the facilities. During the useful life of the field, regarding crude oil production, it passes through three stages: primary, secondary and tertiary recovery. Primary recovery is the first stage in the hydrocarbon production; which means the reservoir pressure is enough to extract the oil. Later, as the pressure decreases, artificial lifting equipment is installed, such as pumps of various types, gas lift equipment and, occasionally, the stimulation of the reservoir. Primary production normally reaches less than 25% of oil in situ. Secondary recovery improves oil production by increasing the pressure of the reservoir, through the improvement of the water pressure, that is the product of the injection of this in the lower levels of the reservoir, or by the increase of gas pressure through the reservoir. The gas injection is made in the upper levels of the geological structure (Ego and Orihuela, 2014; Osinerg, 2005; US EPA, 2000).

The tertiary recovery, unlike the previous two stages, involves the injection of unusual materials in the reservoir, to mobilise oil and be subsequently extracted with this product. Currently, there are not tertiary recovery fields in Peru.

From the available information, it can be inferred that, for Peru, the variation in the production of crude oil and liquid hydrocarbons would depend on the production of the producing or active wells, the existence of injection wells and the wells drilled in the development stage (Ego and Orihuela, 2014; Osinerg, 2005; US EPA, 2000).

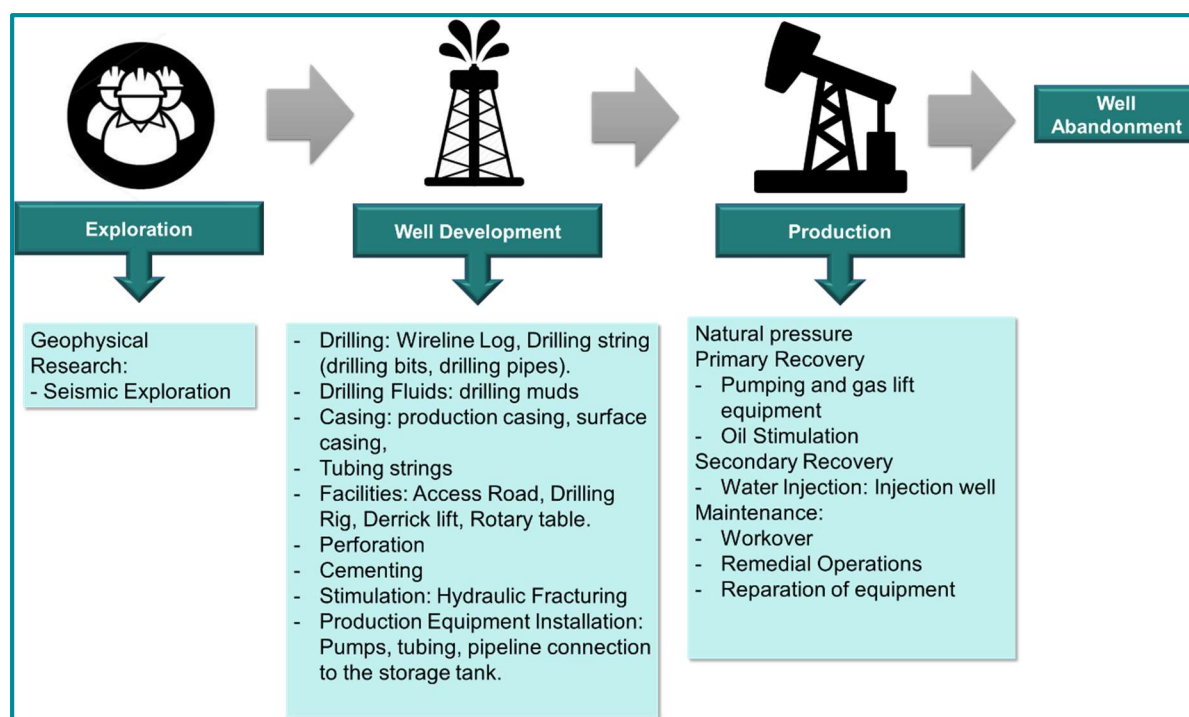


Figure 5: Operative functions, materials and equipment needed in petroleum extraction process (US EPA, 2000).

## 2.6. Agility Concept in the Petroleum Industry

Ganguly et al. (2009), Putnik, 2001 and Yusuf, Musa *et al.* (2014) indicate that the Agility is a capability for fast adaptability in order to respond rapidly to market needs and opportunities, when these needs are unpredictable, uncertain and are likely to change.

Likewise, most studies about the Agility have been directed to the manufacturing industry since the 1990s. According to Garbie and Al-Hosni (2014), the first study directed to the petroleum companies was conducted by Garbie (2011), where a Fuzzy Mathematical Approach is proposed to measure the Agility level of famous two international companies (Yusuf, Sarhadi and Gunasekaran, 1999; Garbie, 2011; Garbie and Al-Hosni, 2014). In the same way, other studies are directed to evaluate the supply chain agility in petroleum sector, measuring its competitiveness and business performance (Menhat and Yusuf, 2018; Yusuf *et al.*, 2014; Yusuf, Musa *et al.*, 2014).

The agile system is known in the O&G industry as the ability to respond, survive and succeed in the current uncertain environment. To do so, petroleum companies have to respond quickly and effectively to change the rates of production according to market demand and instability in oil prices (Elsaghier, 2017; Garbie, 2011; Garbie and

Al-Hosni, 2014). These required changes can occur in several levels within the company, e.g. in exploration areas, drilling a well, production strategies, and technology (Garbie and Al-Hosni, 2014).

Summarising the mentioned concepts, the implementation of agility in operative functions of a petroleum company would control the economic impact due to the variation of crude oil price (Christopher, 2000), through developing production strategies, managing its internal resources and capabilities (Angel-Montoya, 2014; Martén and Whittaker, 2015; Saad, Udin and Hasnan, 2014).

## **2.7. Agility Enablers for a Petroleum Company**

Many researches are focused on the study, application and suggestion of different agility enablers for manufacturing industry. For instance, Gunasekaran (1998), Yusuf, Sarhadi and Gunasekaran (1999) and Bottani (2009) propose business strategies, lean tools, technology development among others as agility enablers.

Similarly, subsequent studies such as Raj *et al.* (2013), under a mathematical model using the Graph Theory approach, define five major enablers to represent an agile system that are evaluated among them and their performance in a single manufacturing organization. Such enablers are management responsibility, manufacturing management, workforce, technology and manufacturing strategy.

Avazpour, Ebrahimi and Fathi (2014) suggest a framework to identify the most appropriate agility enablers to be implemented by companies. This research is made under a fuzzy Prioritization Method to determine weights of the agility attributes and Similarity-Based Approach in order to rank the agility enablers. In this study, the agility enablers considered are Team building, Hardware, tools and equipment, Supply chain management, Concurrent engineering, Information technologies, Knowledge management, Electronic Commerce, System integration and database management.

For the case of the Agility in the Supply Chain, Sharif, Ismail and Reid (2006) propose a conceptual framework that explains the design, structure, implementation and alignment of supply chain agility based on two elements: product information and behaviour/relationship of supply chain. In contrast, in the same year Lin, Chiu and Chu (2006) propose a more complete conceptual model where there are key factors identified such as the agile goals, drivers, capabilities and four main enablers that help to achieve agility in Supply Chain: Process Integration, Collaborative Relationship, Information Integration and Customer sensitivity. See Figure 6.

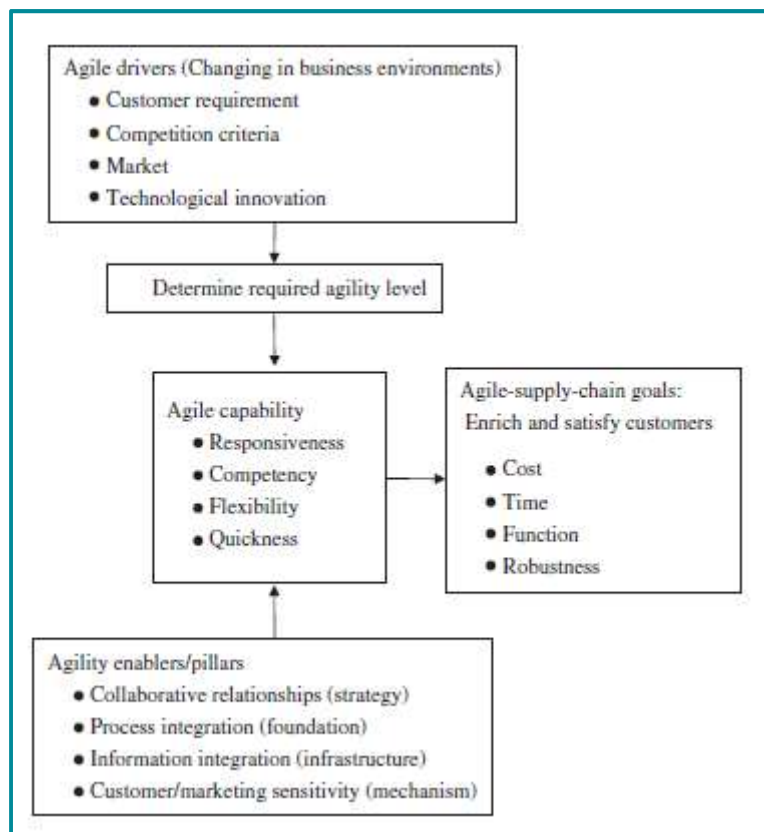


Figure 6: Conceptual Model of agile supply chain (Source: Lin, Chiu and Chu, 2006)

Additionally of previous mentioned research studies, Garbie (2011), Yusuf et al., (2014), Yusuf, Musa et al. (2014) and Abubakar (2014), propose in recent investigations, specific agility enablers applied to O&G companies, which can be classified in four main pillars: production strategies, level of qualifying human resources, technologies, and organization management systems, used by Garbie and Al-Hosni (2014) in their study about the agility level measurement on petroleum companies.

From the variety of concepts proposed by the Literature Review and with the purpose of studying the internal capabilities of the petroleum company as well as its relationship with the supply chain, seven agility enablers are suggested in order to be applied in this case study. See Figure 7 (Chima, 2007; Garbie and Al -Hosni, 2014; Lee, 2002; Lin, Chiu and Chu, 2006; Sharif, Ismail and Reid, 2006).

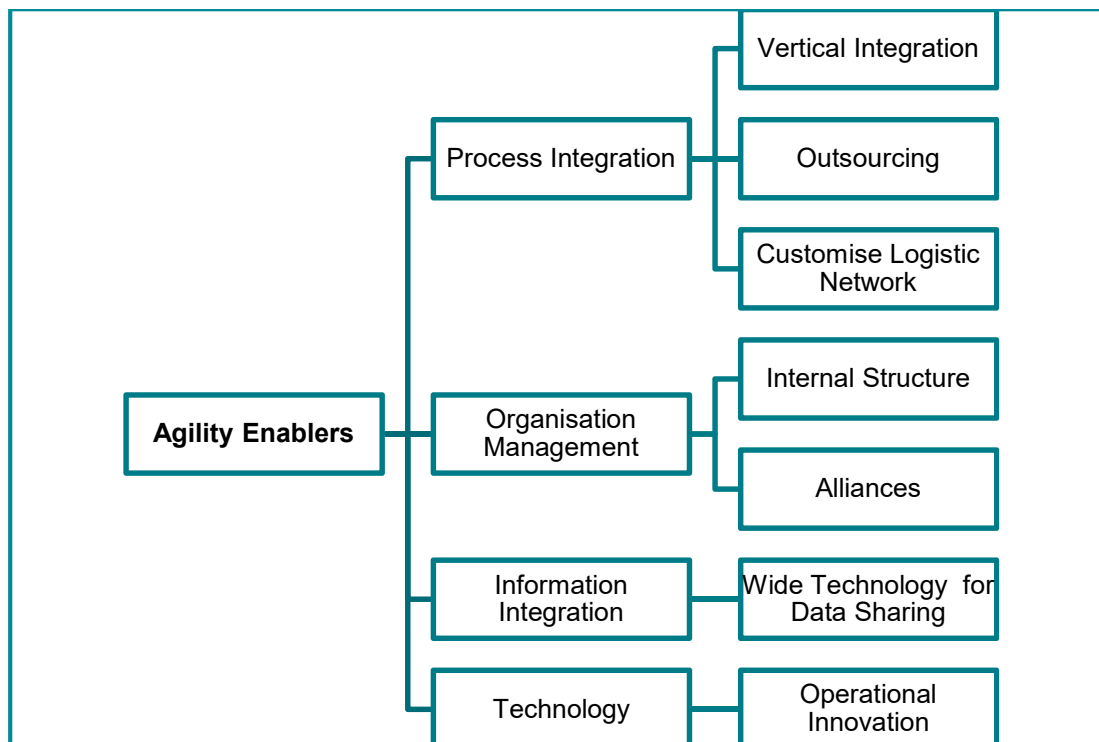


Figure 7: Agility Enablers for a Petroleum Company (Chima, 2007; Lin, Chiu and Chu, 2006)

The **Process Integration** means the alliance between partners in a network that cannot compete independently due to the fact each one adds value to the product (Agarwal et al., 2016; Lin, Chiu and Chu, 2006; Yusuf, *et al.*, 2014).

Chima and Hills (2007) consider three enablers applied in the object of study: Vertical Integration, Outsourcing and Customise Logistic Network.

In the *Vertical Integration*, the companies extend their capabilities to cover functions done by customers or suppliers (Pitt and Koufopoulos, 2012). For this reason, many companies expand their services to link functions that give an integrated and balanced solution to the exploration and production activity. Therefore, these integrated services allow minimizing risks of exchanging information, costs and coordination's time (Chima, 2007).

The *Outsourcing* allows the access to higher skills, innovation and cost reduction. Thus, achieving flexibility in how human resource is used (Oshri, Kotlarsky and Willcocks, 2015; Yusuf, *et al.*, 2014). Chima (2007) affirms that the outsourcing is an alternative of Vertical Integration where a service is contracted with third-parties to provide functions that cannot be developed internally. Both concepts are considered complementary and applicable in the petroleum industry, where approximately 40% of the activities are currently outsourced (Agarwal et al., 2016; Menhat and Yusuf, 2018).

Finally, the *Logistic Network* is related to achieving the logistics efficiency among the

companies involved in the Supply Chain, which involves sharing information and resources in order to obtain visibility and flexibility (Angel-Montoya, 2014). Similarly, the improvement of the Logistics implies the customisation of the Logistic Network, focusing in the transportation and Inventory in the Upstream Petroleum Industry (Agarwal et al., 2016; Chima, 2007).

The second enabling-attribute is the **Organisation Management**, which includes organizing tasks between workers, the organization structure and the process used to control the organization management levels where the enablers in petroleum companies are based on the creation of knowledge through social interactions. In addition, this attribute also involves production support, production planning and control, quality assurance, purchasing, maintenance, marketing, engineering, human resources, finance, and accounting (Garbie, 2011; Lin, Chiu and Chu, 2006).

Furthermore, according to Garbie and Al-Hosni (2014) the knowledge and value are also created through petroleum companies in the oil development processes by themselves, from the exploration phase to the end point.

An optimal relationship can help the companies to achieve cost reductions, operational efficiency and flexibility (Abubakar, 2014; Lin, Chiu and Chu, 2006).

For example, in the exploration and development phases, most of the companies enter into joint ventures to be financially strong (Ernst and Steinhubl, 1997; Garbie and Al-Hosni, 2014). The Partnerships with Specialists and the Outsourcings Contracts are strategic to achieve technological advances and obtain complementary capabilities, low-cost operational skills, geographic experience and know-how (Ernst and Steinhubl, 1997; Harland, 1996).

The third enabling-attribute is the **Information integration**, which includes the ability to use *Information Technology* to share data between buyers and suppliers (Lin, Chiu and Chu, 2006). The Internet plays an important role not only to show the real-time data of inventory or transportation, but also to enable sharing information about work-process changes, technology's needs to exploration and production, through a Modelled System (Yusuf, Musa *et al.*, 2014). These new requirements or activities changes are included as data and are shared with the employees, providers and interested parties. At that time, a flexible, adaptable and cost-efficient operation is achieved. (Chima, 2007; Lee, 2002).

Finally, the technology plays an important role to enhance agility in a petroleum company. These benefits are reflected in the development of projects in exploration (seismic reflection, gravity, magnetic, electrical), drilling and transportation due to the reduction of exploration time, the flexibility enhancement in selecting a drill site, and improvement in understanding and controlling the production processes (Garbie,

2011; Lin, Chiu and Chu, 2006). Therefore, the objective of applying operational innovation along the operations is to discover new ways of working by searching and optimizing the core business links (Chima, 2007; Garbie, 2011).

Furthermore, based on the agility enablers showed in figure 7 and in-depth Literature Review, twenty-one more specific agility enablers applied in petroleum industry are suggested for the case study. See Table 1.

Table 1: Specific Agility Enablers in Petroleum Company (Chima, 2007; Lin, Chiu and Chu, 2006)

AGILITY ENABLERS	IT	Specification	References
<b>Vertical Integration</b>	1	Vertical Integration between Contractors	(Al-Obaidan and Scully, 1993; Chima, 2007; Cibir and Grant, 1996)
<b>Outsourcing</b>	2	Supplier location close from oilfield	(Dauda and Yusuf, 2004; Hussain, Assavapokee and Khumawala, 2006)
	3	Optimal Pricing Strategy	(Chima, 2007; Röthlisberger, 2005)
	4	Long term purchasing agreement	(Agility.com, 2017; Chima, 2007; Dauda and Yusuf, 2004; Röthlisberger, 2005)
<b>Customise Logistic Network</b>	5	3PL Contractor for Internal transportation and warehousing	(Agarwal, Sharma and Mathew, 2016; Herrera, 2012)
	6	Suppling materials in production line	(Chima, 2007; Hussain, Assavapokee and Khumawala, 2006)
<b>Internal Operations</b>	7	Re-using or recycling old tools	(Garbie and Al-Hosni, 2014)
	8	Decentralisation of Operational decision making	(Cibir and Grant, 1996)
	9	Application of TPM and TQM	(Agarwal, Sharma and Mathew, 2016; Bieker, Slupphaug and Johansen, 2006)
	10	Kanban Application	(Agarwal, Sharma and Mathew, 2016; Garbie, 2011; Sakhardande, 2011)
	11	Reduced design cycle time and Lead time	(Bieker, Slupphaug and Johansen, 2006; Menhat and Yusuf, 2018; Röthlisberger, 2005)
<b>Alliances</b>	12	Reduction in Manpower	(Röthlisberger, 2005)
	13	Contractual relationships with other operating companies for sharing materials	(Dauda and Yusuf, 2004; EY, 2015)
	14	Execute the field's overall development	(Ernst and Steinhubl, 1997; EY, 2015)
<b>Wide Technology for Data Sharing</b>	15	Collaborative bidding and rate negotiations with current contractors	(Chima, 2007; Röthlisberger, 2005)
	16	Sharing information on reserves, innovations and operational's cases among companies of the sector	(Chima, 2007; Osinerg, 2005)
	17	Sharing Information into the company to integrate the production operations	(Oracle, 2011; Olinto, Oliveira and Rocha, 2018)
<b>Operational Innovation Technology</b>	18	Cross-channel Coordination	(Chima, 2007; Röthlisberger, 2005)
	19	Production Optimisation and changing the nature of the work	(Agility.com, 2017; Bieker, Slupphaug and Johansen, 2006; Shuen, Feiler and Teece, 2014)
	20	Early supplier involvement in product technology	(Dauda and Yusuf, 2004; Olinto, Oliveira and Rocha, 2018)
	21	Engineer-to-order for tools and equipment	(Cibir and Grant, 1996; Dauda and Yusuf, 2004; Shuen, Feiler and Teece, 2014)



### **3. Research Methodology**

#### **3.1. Research Philosophy**

According to Bell, Bryman and Harley (2019), the way of conducting a research is not only by its theoretical orientation, but also includes a philosophical assumption framework. The philosophy seeks to make explicit assumptions in three spheres: Ontology, Epistemology and Methodology or Research Strategy. This last is further explained in the next section 3.2.

The Ontological consideration determines whether the studio is concerned about the 'nature of reality'. It means, if the study phenomenon exists in an objective way, external to the researcher (objectivism), or whether this observer 'made it real' by human activities (constructionism) (Bell, Bryman and Harley, 2019). This study can be divided in two main parts, the first part is the analysis of the historical data in order to define the modelling of production cost and make the simulation of crude oil price scenarios. The second part is related to the definition of the agility enablers to be applied in each scenario. The first part of the research implies an objectivism approach due to the fact it is worked with historical data and mathematical models. By contrast, the second part is worked in a constructionism approach since the subjective determination of the agility enablers is based on previous articles, theory, newspapers and other secondary resources (Collis and Hussey, 2009).

Similarly, in order to understand how knowledge of the reality can be gained, the Epistemology consideration gives two options: Positivism and Interpretivism (Bell, Bryman and Harley, 2019). Unlike the Positive approach, this research will develop in each investigation stage an interpretive understanding from the results of the previous stage (Bell, Bryman and Harley, 2019; Collis and Hussey, 2009).

#### **3.2. Research Strategy**

Collis and Hussey (2009) propose a Research strategy classification divided in four basis: Objective, Process, Outcome and Logic. This study is focused in the type of research shaded in grey of the following table 2:

Bell, Bryman and Harley (2019) defines a difference between a Deductive and Inductive research based on terms of consequentiality. This study is worked under the Deductive Research framework since all the findings or observations are produced based on theory and literature review, beginning with general inferences that then are tested through obtaining the final result (Bell, Bryman and Harley, 2019; Collis and Hussey, 2009).

Table 2: Classification Basis for Research Strategy (Collis and Hussey, 2009)

Basis of Classification	Type of Research			
Logic	Deductive		Inductive	
Objective	Exploratory	Descriptive	Analytical	Predictive
Outcome	Applied		Basic	
Process	Quantitative Method	Qualitative Method	Mixed Method	

In terms of the Research objective, this study combines a descriptive objective to understand the behaviour of the industry with historical data, and a predictive objective in order to forecast the petroleum production under simulation scenarios (Bell, Bryman and Harley, 2019). However, the main objective of the study is to link the application of agility enablers with specific scenarios of crude oil price fluctuation. This approach is considered as a new study concept, due to most of the previous studies were focused on measuring the agility level of the companies or its performance after the application of these agility enablers (Garbie and Al-Hosni, 2014).

Thus, the Exploratory Research objective is suitable to this study because this kind of research is applied to a little known study area, that will help to obtain a better understanding of a problem without providing a conclusive solution of a problem (Collis and Hussey, 2009; Kumar, 2019).

Furthermore, in terms of Research outcome, this paper is developed under the 'Applied' case study, where a particular context is examined to solve a specific and existing problem (Crowther and Lancaster, 2008; Kothari, 2008).

Finally, the study is developed under Mixed Methods which integrate quantitative methods for the analysis and modelling of historical data, as well as the simulation of crude oil price fluctuation. Otherwise, qualitative methods are also applied to suggest agility enablers in the production process using the document analysis method (Bryman, 2016; Watkins and Gioia, 2015).

### 3.3. Research Design

Bell, Bryman and Harley (2019), Bryman (2016), Hesse-Biber and Johnson (2015) and Watkins and Gioia (2015) suggest a variety of Mixed Methods designs, including: Convergent Parallel, Exploratory sequential, sequential Explanatory and Embedded. The mixed-method sequential explanatory is applied in this paper due to the fact it allows interconnecting various questions of the study through sequential approaches focusing on a common objective (Creswell, 2014).

The design consists in a quantitative method followed by qualitative method linked by

an intermediate stage, as is summarised in the Figure 8. The first stage is about the collection, analysing and modelling of historical data. With these models, a Simulation System is built to obtain two profit margin ratios as final result, after defining the future scenarios of crude oil price fluctuation and calculating them in the simulation system (Creswell, 2014; Ivankova et al., 2006; Subedi, 2016).

In the intermediate stage, four study parameters are defined, where two of them are the profit margin ratios, and the other two are related to the crude oil price variation. A linguistic labelling is assigned to these four parameters under a classification criterion (Ivankova et al., 2006; Lin, Chiu and Tseng, 2006; Subedi, 2016).

In the next stage, the Document Analysis Method is applied, where previous studies reports, papers, research and articles, among others, are analysed. This method involves selecting the ones which relate to the study parameters in linguistic terms with the application of agility enablers in O&G sector (Bowen, 2009; Ivankova et al., 2006).

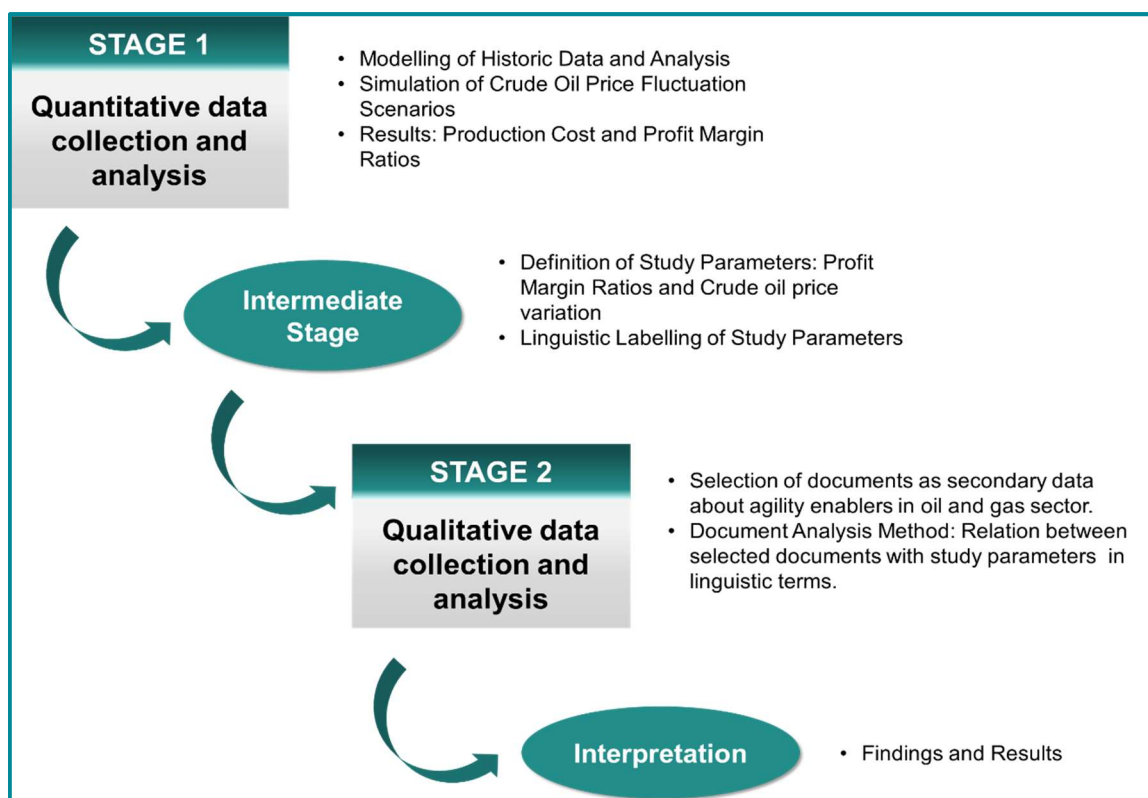


Figure 8: Mixed-Method Sequential Explanatory Design (Ivankova et al., 2006; Subedi, 2016).

## 4. Methods and Data Collection

This section will explain the methods used in the study. Firstly, the Production Cost is modelled in section 4.1; then, this model will be employed as an equation to build the simulation system, where in addition, input and output variables are assigned and are explained in section 4.2.

The Intermediate stage is developed in section 4.3 and finally the Stage 2 in section 4.4.

### 4.1. Modelling of Total Production Cost

The case study is located on Block X, in Peru's northwest area, and the secondary historical data from 1998 to 2018 is obtained of public source detailed in this and the following sections. Likewise, the crude oil production function is being considered at wellhead; therefore, administrative and financial costs are not included.

#### 4.1.1. Cost Production Function – Translog Model

Chermak and Patrick (1995) use a translog model for estimating a cost function for extraction of natural gas in United States whose variables are time, age of wells and monthly production. Similarly, Gao, Hartley and Sickles (2004) also use the same translog model to determine a production cost function based on exploration, development and operational costs for Saudi Arabia. From this last study, Ego and Orihuela (2014) applied this model to estimate the total production cost function of crude oil in Peru represented by equation (1):

Where subscripts  $i$  and  $t$  correspond to the northwest and jungle areas of Peru.

$$\ln(PC) = \beta_0 + \beta_q \ln(q_{it}) + \sum_{j=1}^k \beta_j \ln(W_{j,it}) + \varepsilon_{it} \quad (1)$$

As same as Ego and Orihuela (2014), the Cobb-Douglas type cost function, Equation (2) is derived, applying logarithms to both member of the function to comply with the duality theorem (Ego and Orihuela, 2014; Morocho, 2016). As is indicated in equation (3):

$$TC = a Q^\alpha W^\beta \quad (2)$$

Where:

$a$ ,  $\alpha$  and  $\beta$  are positive constants and  $\beta=1-\alpha$

$Q$  is the production level

W Production factor cost

$$\ln(PC) = \ln(a) + \alpha \ln(Q) + \beta \ln(W) \quad (3)$$

From equation (3) the final equation (4) is derived to apply in this case study:

$$\ln(PC_t) = \beta_0 + \beta_q \ln(Q_t) + \sum_{j=1}^3 \beta_j \ln(W_{jt}) \quad (4)$$

Where:

t = Time Series from 1999 to 2018

The Historical Data of the following variables have been obtained from PERUPETRO for Block X located in north-western Peru. The access to this data is public and is granted based on Peruvian citizenship in application of the Law N°27806 - Law on Transparency and Access to Public Information.

Q = Production Level in Barrels (BBL)

PC = Total Production Cost (Not including Exploration Cost)

The information of the following variables has been calculated according to equation (10).

$W_1$  = Development cost and lease equipment factor cost for primary oil recovery. To assess the effect of the wells drilled on the production cost function by year.

$W_2$  = Operations factor cost of the primary oil recovery. To assess the effect of producing wells on the production cost function by year.

$W_3$  = Operations cost, and lease equipment factor cost for secondary oil recovery. To assess the effect of injector wells on the production cost function by year.

$\beta$  = Intercept.

$\beta_q$  = Total cost elasticity - production level.

$\beta_1$  = Total cost elasticity – Development and lease equipment factor cost for primary oil recovery

$\beta_2$  = Total cost elasticity – Operations factor cost of the primary oil recovery

$\beta_3$  = Total cost elasticity – Operations cost, and lease equipment factor cost for secondary oil recovery

Similarly, there is a restriction of homogeneity characteristic of grade one in the input costs. For this case, the sum of the price-cost elasticities of the inputs must be one, as seen in equation (5). This means that, if all input costs increase by the same

proportion, the total production cost must also increase on that same scale (Ego and Orihuela, 2014).

$$\sum_{j=1}^3 \beta_j = 1 \quad (5)$$

#### 4.1.2. Crude Oil Price – Multiple Regression

The company of the case study sells the crude oil produced to PERUPETRO. The sales price for the northwest area is comprised by the average of the international prices: Forties (UK Source), Oman (Oman Source) and Suez Blend (Egypt Source), due to the similarity of the type of crude oil extracted in these areas respect to the northwest area of Peru. This similarity is determined because of the degree of viscosity of hydrocarbon compounds in the aforementioned areas, which level in Block X is 34.20° considered as light crude. Classified by the international API parameter (McKinsey, 2019; Osinerg, 2005; PERUPETRO, 2019).

Also, as it is indicated in the Literature Review (section 2.3), the WTI and Brent are the international markers that serve as an indicator for setting the price of other crude oils. Therefore, the relationship between them and the average of the three types of crude oil produced in the northwest zone is analysed. For this, the Multiple Regression is used to measure the arithmetic relationship between the factors described below (Linoff and Berry, 2011; Weisberg, 2014):

$$COP_t = \alpha_0 + \alpha_1 * WTI_t + \alpha_2 * Brent_t \quad (6)$$

Where:

t = Time Series from 1999 to 2018

COP = The sale price of crude oil from the producing company to PERUPETRO, equal to the average of Forties, Oman and Suez Blend price. This information has been obtained from the historical data of PERUPETRO (PERUPETRO, 2019).

WTI and Brent = International sale price. This information has been obtained from the U.S. Energy Information Administration (EIA, 2010; EIA, 2019b).

#### 4.1.3. Production Level – Linear Regression

The Production Level is an input variable for the Translog Model to be applied as part of the simulation system, the relationship of this variable respect to the crude oil price is analysed for the period 1999 to 2018 (Historical Data from PERUPETRO). The final regression function obtained will be used to calculate the production level for the projected period: 2019 to 2028.

Firstly, as it was explained in section 2.4. from the Literature Review, a previous study carried out by La-Rosa (2018) determines a positive correlation between international

crude oil prices and the production decision in Peru. Figure 4 shows that this relationship has a positive correlative tendency; however, this information reveals the behaviour at a national level and not for the specific case study.

For this, the historical data of the Production Level (Q) and the crude oil price (COP) are analysed. Indeed, the relationship between these variables is determined by a linear regression model, which is the most commonly used predictive modelling technique, in order to measure the arithmetic relationship between the factors described (Lind, Marchal and Mason, 2004). See the Equation (7):

$$Q_t = \gamma_0 + \gamma_1 * COP_t \quad (7)$$

#### 4.1.4. Unit Costs of Production Factors – Linear Regression

The unit production costs ( $\omega_1, \omega_2, \omega_3$ ) are taken from EIA<sup>5</sup>, who analysed these costs for the years 1994 to 2009 in the different regions of the USA<sup>6</sup> (EIA, 2010). This data is taken for the case study since there is not national data available.

These prices are managed by a small group of service companies that work worldwide, with equivalent service price lists. Additionally, the values corresponding to the west coast of United States (California and West Texas) will be used due to its similarity to the northwest area of Peru, both in geological age and proximity to the sea (Ego and Orihuela, 2014; EIA, 2010; EIA, 2019b; Osinerg, 2005).

Finally, these costs should be taken to the Peruvian reality of the case study. So that, the costs are calculated based on the number of drilled, producing and injection wells. This information was obtained from PERUPETRO in annual series (EIA, 2010; EIA, 2019b; PERUPETRO, 2019).

Additionally, the data is projected to the period from 1999 to 2018 using seasonal indices as multiplier factors, taken from the averaged of: Fuel Consumer Price Index (CPI), the Gross Domestic Product for Peru's Extractive Sector (GDP) and the Crude Oil Price Index (COPI), considering as Base Index 1994=100. These values were obtained from INEI, BCRP, World Bank and EIA. (Keat and Young, 2003; World Bank, 2019; BCRP, 2018; INEI, 2019; EIA, 2010; EIA, 2019b).

$$Total.Index_t = \frac{CPI_t + GDP_t + COPI_t}{3} \quad (8)$$

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<sup>5</sup> US Environmental Protection Agency

<sup>6</sup> United States of America

Finally, after obtaining the values for the period 1999 and 2018, the relationship between the Total Index and the variation in the crude oil price is analysed in order to project these values to the simulation period (2019 to 2028), through Regression Linear as shown in Equation (9)

$$Total.Index_t = \theta_0 + \theta_1 * COP_t \quad (9)$$

This equation is used to calculate the current value of operating costs, as shown in equation (10):

$$W_{jt} = \frac{\omega_j * Total.Index_t * D_{jt}}{100} \quad (10)$$

Where:

$j = 1,2,3$ ;  $t =$  from 1999 to 2018

The data of the following variables has been obtained from PERUPETRO Historical Data for Block X:

$D_{1t}$  = Number of drilled wells on period  $t$ .

$D_{2t}$  = Number of producing wells on period  $t$ .

$D_{3t}$  = Number of Injection wells (drilling y producing) on period  $t$ .

The following variables have been obtained from the U.S. Energy Information Administration (EIA) series, normalised to 1994.

$C_1$  = Development price and lease equipment factor price for primary production.

$C_2$  = Operation factor price of primary oil recovery.

$C_3$  = Lease Equipment price and operation factor price of secondary oil recovery.

## 4.2. Simulation Method – Deterministic System

In this section the scenarios of crude oil price fluctuation for the period from 2019 to 2028 are explained. These are considered as input variable of the simulation system in order to calculate the output explained in the Figure 9 (Lewis and Orav, 1989; Lewis-Beck, Bryman and Liao, 2004).

In this figure is observed that in addition to WTI and Brent prices, two additional input variables are considered:

$C_j = C_1, C_2, C_3$

$D_{jt}$  = Number drilled, producing and injection wells. The estimation of the variable is based on the parameters explained in section 4.2.2.



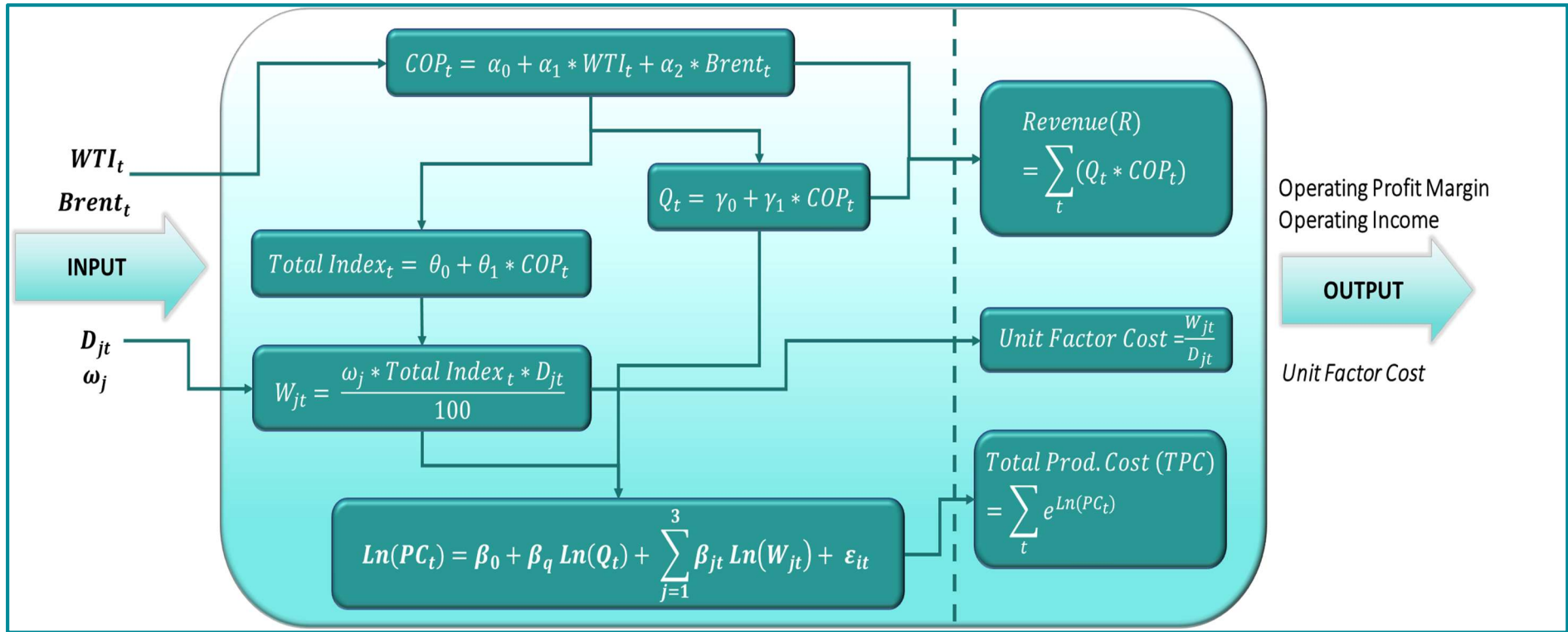


Figure 9: Simulation System (Lewis and Orav, 1989; Lewis-Beck, Bryman and Liao, 2004).

## System Input Variables

### 4.2.1. Crude Oil Price Scenarios

Currently, studies such as Degiannakis and Filis (2018); Herrera, Hu and Pastor (2018), Kang et al. (2009), Wang et al. (2018), Zhang et al. (2018) and Zhang et al. (2019) evaluate the behaviour of crude oil prices through the years, and some of them present mathematical models to project future values and predict their volatility. Such is the case of Zhang et al. (2018) who employed an iterated combination approach to examine crude oil price predictability with 18 macroeconomic variables as predictors and 18 technical indicators. Otherwise, Degiannakis and Filis (2018) and Wang et al. (2018) made the forecast of crude oil futures prices using two different modelling frameworks. The first one used financial commodities and macroeconomic assets, while Wang et al. (2018) predicted the price volatility of crude oil's futures market based on Internet Concern through individual frequency.

From this literature review, it is observed that projecting crude oil prices involves various macroeconomic factors; in addition, finding an accurate tool to forecast them is complicated by the fact that the market dynamics tend to vary substantially over time (ECB, 2015).

Due to this, and because of the selection of a forecasting tool is not part of the study object, price fluctuation scenarios are obtained from projections already made by EIA (2019a) in the case of the first scenario. In the case of the following four scenarios, random variables were used with a different price fluctuation and with a specific trend, as shown in the following table 3:

Table 3: Trend for Scenarios of crude oil price fluctuation (BBC, 2016, ECB, 2015, EIA, 2019a).

SCENARIOS				
1	2	3	4	5
Slow Increase	Fast Increase	Unsettled	Fast Decrease	Slow Decrease

Scenario 2 of fast increase is suggested considering that there were periods of high price historically. This case leads to more drilling activity in the near term, but at the same time there is an increase in costs and fewer easily accessible resources; which can generate the decrease in production (EIA, 2019a).

Also, the crude oil prices can behave very differently over time depending on the driver

factor. To answer this premise, the scenario 3 is proposed, since historically crude oil prices have varied between being stable, trending upwards and falling abruptly. This could be explained by changes in oil supply, oil demand and oil inventories (ECB, 2015; Kang, Ratti and Vespignani, 2017).

By last, since mid-2014 to 2016, crude oil prices have slumped 70% mainly because of oversupply as indicated in the section 2.3 of the literature review. In addition, Goldman Sachs, the world's largest investment banking group, warned that oil prices could go down to \$20 per barrel (BBC, 2016). Therefore, both scenario 04 and 05 are proposed, which consider an accelerated and slow decrease of the price, respectively.

#### 4.2.2. Number of drilled, producing and injection wells

The drilling of wells for the development of the different fields, depends on the Reservoir Engineering, where both a static and a dynamic analysis are carried out, through the evaluation of the production behaviour of each well, and the field modelling through the use of specialized simulators (Ego and Orihuela, 2014). This level of detail escapes from the study subject; in consequence, the number of drilled, producing and injection wells is estimated considering the following factors:

- a. Production Level per Well (PL): Tamayo et al. (2015) explained the phases of crude oil production, which had the behaviour shown in Figure 10. As the years go by, the reserves produce less BPD, which leads to the need to use secondary recovery methods, as well as the need to drill more wells to keep the volume of hydrocarbons extracted, which makes the operation more expensive (Osinerg, 2005; Tamayo et al., 2015).

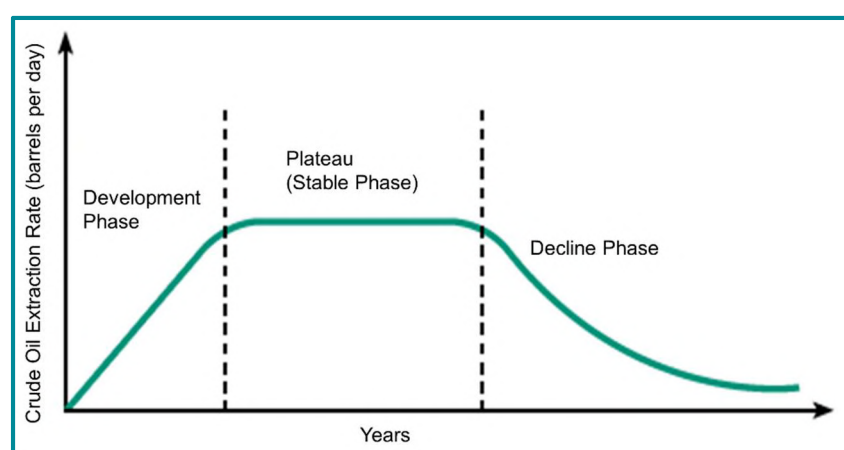


Figure 10: Physical Production Phases of a Crude Oil Reservoir (Source: Tamayo et al., 2015)

The case study is located in Block X in the Talara basin. This block is a mature field with more than one hundred years of production. In fact, this production level per well is indicated in Figure 11 (CNPC, 2019; PERUPETRO, 2019).

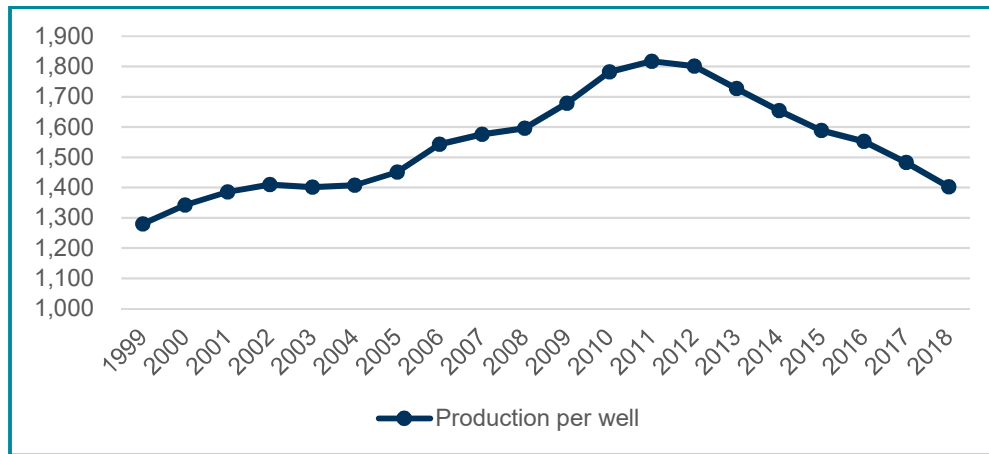


Figure 11: Production Level per well from 1999 to 2018 (CNPC, 2019; PERUPETRO, 2019).

There is no study that indicates whether the Block is in a stable or declining phase. However, according to Figure 11, it can be estimated that for the following years the production per well can range between 1200 and 1400 BPD, due to the decreasing behaviour of physical production from the year 2011 up to now (CNPC, 2019; PERUPETRO, 2019).

After this explanation, the study will take random values between 1200 and 1400 BPD, in each scenario proposed for the period  $t = 2019$  to 2028.

$$PL_t = \text{Random between } [1200; 1400] \quad (11)$$

- b. Number of Drilled Wells ( $D_1$ ): As indicated above, the decision on the number of drilled wells per period requires a more in-depth study on the reservoir. Therefore, according to the historical behaviour of the company, random values between 50 and 90 wells per period are considered for the simulation scenarios (Ego and Orihuela, 2014; PERUPETRO, 2019).

$$D_1(t) = \text{Random between } [50; 90] \quad (12)$$

- c. Number of Producing Wells ( $D_2$ ): Calculated by the equation (13):

$$D_2(t) = \frac{Q_t}{PL_t} \quad (13)$$

- d. Number of Injection Wells ( $D_{31t}, D_{32t}$ ):  $D_{31t}$  is the number of injection wells drilled

in period  $t$  and  $D_{32t}$  is the number of active injection wells in period  $t$ .

In order to calculate  $D_{32}$  the study carried out by Carvajal (2012) is used as the basis, where the production system of a crude oil field in Ecuador is analysed and optimised (region next to Block X). Under simulation scenarios, it is determined that the flow of extracted crude oil increases by 2.76% when injection wells are used. This value corresponds to 2.69% of the level of final production obtained.

This study is taken as a reference based on the similarity with the case study regarding the field age and the proximity of the block studied (Carvajal, 2012; Osinerg, 2005).

$$D_{32}(t) = \frac{Q_t * 2.69\%}{PL_t} \quad (14)$$

$$D_{31}(t) = D_{32}(t) - D_{32}(t - 1) \quad (15)$$

Where:

$$D_{31}(t) \geq 0 \quad \forall t$$

$$\text{If } D_{31}(t) < 0 \rightarrow D_{31}(t) = 0$$

$D_{32}(0)$  is the Drilled injection wells in 2018 obtained from PERUPETRO historical data.

## **System Output**

### **4.2.3. Profit Margin Ratios: Operating Income and Operating Profit Margin**

The Profit Margin is considered as an evaluation ratio for O&G companies in many studies as Bala (2013), Iskakov and Yilmaz (2015) and Menhat and Yusuf (2018). This last study focuses on its investigation choosing the influencing factors as a performance measure for the oil and gas supply chain. In this study, three out of five companies interviewed of the sector indicate that most of the O&G companies are running by the profit driven organization, and most of the indicators chosen are influence by cost.

Furthermore, Iskakov and Yilmaz (2015) assess the performance of four major companies of the sector: BP, Exxon Mobil, Chevron, and Royal Dutch Shell. The Operating Profit Margin is used as a ratio of evaluation in the financial analysis by each company, and its competitiveness benchmark is determined.

Gallagher and Andrew (2007) conceptualise the operating profit margin as a performance ratio used to calculate how much profit remains out of the revenue after all operating expenses are subtracted. This ratio named operating income is calculated by dividing earnings before interest and taxes, as it is shown in equation (18).

For the case study, the mentioned ratio is used to the projected period from 2019 to 2028, as a total value without considering the exploration costs within the operating income. Observing the following equations:

$$Revenue(R) = \sum_t(Q_t * COP_t) \quad (16)$$

$$Total\ Production\ Cost(TPC) = \sum_t e^{Ln(PC_t)} \quad (17)$$

$$Operating\ Profit\ Margin(OPM) = \frac{R-TPC}{R} \times 100\% \quad (18)$$

With equation (9) the performance of the case study will be analysed, comparing the five scenarios and the current situation of the company.

Likewise, in order to measure the financial performance of the company, the variability of the earnings of the operations per year for each scenario will be evaluated, according to equation(19). After that, the variation between years will be analysed to determine if it has a positive or negative tendency (Aboody, 1996; Iskakov and Yilmaz, 2015; Mandal and Goswami, 2010).

$$Operating\ Income\ per\ Year\ (t) = Q_t * COP_t - e^{Ln(PC_t)} \quad (19)$$

### 4.3. Classification criterion for scenarios

After calculating the first stage of this study, the results obtained must be classified in order to begin the qualitative stage.

For this, firstly with the equation(19) the tendency of the Operating Income in the period will be defined for the period 2019 to 2028. These values will be classified in each scenario as detailed in table 4.

Operating Income Variability parameter is classified in variance value terms to analyse the link between the dispersion respect to the average values. Given that, if there is a greater dispersion, there is greater variability. Similarly, to classify the Operating Income Tendency parameter, the median of the annual variations will be analysed in

order to represent the central tendency of these values (Lind, Marchal and Mason, 2004).

After calculating the classification parameters, those are converted into a subjective linguistic expression.

The linguistic labelling concept is used by several studies to deal with complex or ill-defined situations to be reasonably described in conventional qualitative expressions after getting a quantitative parameter (Bolia et al., 2012; Lin, Chiu and Tseng, 2006; Mishra, Mahapatra and Datta, 2014). At the same time, Mishra, Mahapatra and Datta (2014) indicate that most of the agile criteria are subjective when the expert opinion is the only choice that researchers have to capture human perception of the linguistic judgment of criteria's performance levels.

For example, "low" is a linguistic variable rather than numerical, but it expresses a subjective classification of a quantitative situation (Lin, Chiu and Tseng (2006). Bolia, et al. (2012) use this linguistic labelling to classify the performance levels of critical agility parameters. Whereas, Lin, Chiu and Tseng (2006) use it for evaluating the performance ratings of the agility capabilities.

Therefore, considering this literature review and the revision made for the agility enablers in section 2.7, it is proposed to linguistic labelling for the four parameters of the study, as it is shown in table 4.

In the case of labelling for the Crude Oil Price tendency, studies such as Jiao et al. (2014), Onour (2009), Pacheco (2018) and Rizvi (2019) take the expression as a reference. Since a price was considered "normal" when it was \$76 in 2011, and a 'high' price was over \$ 80. Indeed, a 'low' price would be under \$70.

In order to calculate the Crude Oil Price Tendency, the median of crude oil prices fluctuation is analysed in each scenario considering the criteria described in table 4 (Lind, Marchal and Mason, 2004).

Table 4: Parameters and Linguistic Labelling for the case study (Jiao et al., 2014; Lin, Chiu and Tseng, 2006; Lind, Marchal and Mason, 2004).

Parameters Name	Parameters Description	Linguistic Labelling
<b>Operating Income Variation per year (OIV)</b>	$OIV_{t+1} = \frac{\text{Operating Income (t+1)}}{\text{Operating Income (t)}} - 1$ $t = [2019;2028]$	
<b>Variability of Operating Income (A)</b>	$A = \text{Variance of } OIV_{t+1}$ $t = [2019;2028]$	Low Variation → A ≤ 5%
		High Variation → A > 5%
<b>Tendency (B)</b>	$B = \text{Median of } OIV_{t+1}$ $t = [2019;2028]$	Positive → B ≥ 0
		Negative → B < 0
<b>Crude Oil Price Tendency (C)</b>	$C = \text{Median of } COP_t$ $t = [2019;2028]$	High → C ≥ 80
		Normal → C = [70;80>
		Low → C < 70

In summary, the final classification of the scenarios will be divided into four parameters and various linguistic labelling per parameter, as shown in Table 5:

Table 5: Linguistic Labelling per Parameter (Bolia et al., 2012; Jiao et al., 2014; Lin, Chiu and Tseng, 2006; Lind, Marchal and Mason, 2004; Mishra, Mahapatra and Datta, 2014).

Parameter	Linguistic Labelling				
	<b>Crude Oil Price Behaviour</b>	Slow Increase	Fast Increase	Unsettled	Fast Decrease
<b>Crude Oil Price Tendency</b>	High		Normal		Low
<b>Operating Income Variability</b>	High Variation			Low Variation	
<b>Operating Income Tendency</b>	Positive			Negative	

#### 4.4. Identification of Agility Enablers - Document Analysis Method

In this Qualitative stage, the linguistic labelling is applied for the study parameters indicated in table 5 to search the agility enablers in the petroleum sector which are applied in a similar context of the study parameters.



This is performed applying the Document Analysis Method, which is a systematic procedure for reviewing or evaluating documents such as advertisements, agendas, manuals, background papers, books, brochures, diaries, journals, newspapers and so on. The analytic procedure comprises finding, selecting, appraising (making sense of), and synthesising data contained in these documents (Bryman, 2016; Bowen, 2009).

Therefore, the agility enablers considered in the case study are indicated in the literature review for specific cases of application and identified in the upstream petroleum industry (Bryman, 2016; Novikov and Novikov, 2013). These specific Agility enablers are classified based on the linguistic labelling, after analysing and identifying each theoretical document or study that relates the parameters of the case study. See Table 6.

For example, according to Agarwal et al. (2016) and Herrera (2012), the 3PL Contractor for Internal transportation and warehousing is needed for an 'Increase' and 'Unsettled' Price behaviour. Due to the high costs of performing this Customise Logistic, it should be applied in cases of 'High' crude oil price and a 'Positive' Operating Income tendency. The Operating Income variability in any document is not indicated in this example; thus, the 'Low' and 'High' variation was considered in any case.

The table 6 will be used in the Data Analysis section. After finding the final case study parameter for each proposed scenario, the agility enablers, which comply with these parameters in the most expensive operational processes, will be assigned.

Table 6: Classification of Agility Enablers based on linguistic labelling (Bryman, 2016; Bowen, 2009)

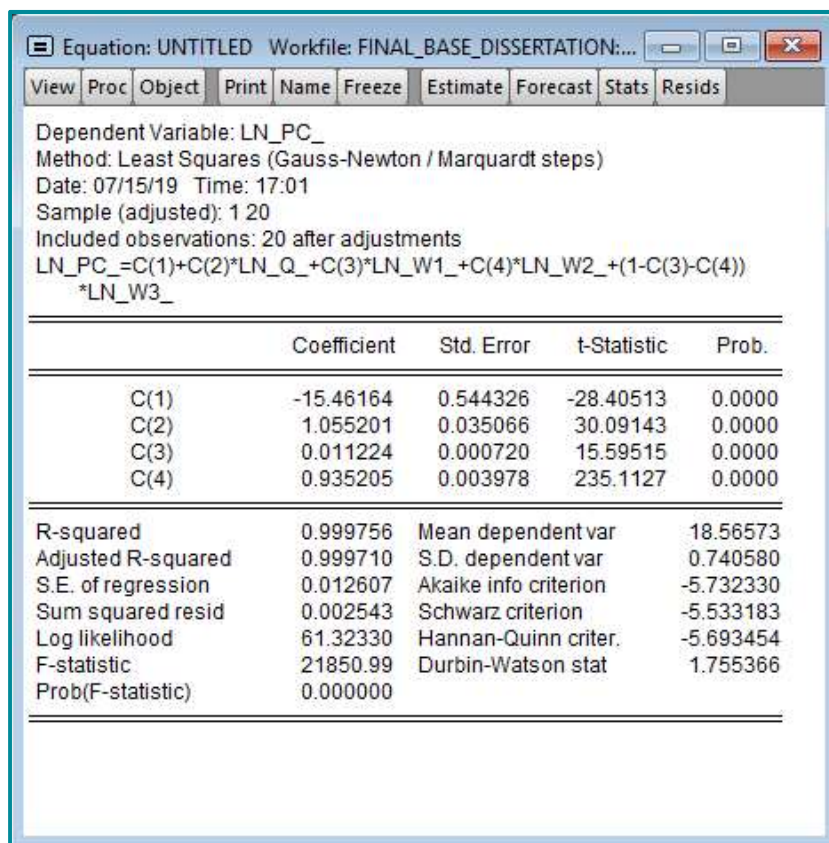
AGILITY ENABLERS	IT	Specification	Parameters Name				References
			Crude Oil Price Behaviour	Crude Oil Price Tendency	Operating Income Variability	Operating Income Tendency	
<b>Vertical Integration</b>	1	Vertical Integration between Contractors	Increase	Normal and High	Low Variation	Positive	(Al-Obaidan and Scully, 1993; Chima, 2007; Cibir and Grant, 1996)
<b>Outsourcing</b>	2	Supplier location close from oilfield	Unsettled and Decrease	Normal and Low	Low and High Variation	Negative	(Dauda and Yusuf, 2004; Hussain, Assavapokee and Khumawala, 2006)
	3	Optimal Pricing Strategy	Decrease	Low	Low Variation	Negative	(Chima, 2007; Röthlisberger, 2005)
	4	Long term purchasing agreement	Unsettled and Decrease	Normal and Low	Low and High Variation	Negative	(Agility.com, 2017; Chima, 2007; Dauda and Yusuf, 2004; Röthlisberger, 2005)
<b>Customise Logistic Network</b>	5	3PL Contractor for Internal transportation and warehousing	Increase and Unsettled	Normal and High	Low and High Variation	Positive	(Agarwal, Sharma and Mathew, 2016; Herrera, 2012)
	6	Suppling materials in production line	Increase and Unsettled	Normal and High	Low and High Variation	Positive and Negative	(Chima, 2007; Hussain, Assavapokee and Khumawala, 2006)
<b>Internal Operations</b>	7	Re-using or recycling old tools	Increase, Decrease and Unsettled	Normal, High and Low	Low and High Variation	Positive and Negative	(Garbie and Al-Hosni, 2014)
	8	Decentralisation of Operational decision making	Decrease	Low	Low Variation	Negative	(Cibir and Grant, 1996)
	9	Application of TPM and TQM	Increase, Decrease and Unsettled	Normal, High and Low	Low and High Variation	Positive and Negative	(Agarwal, Sharma and Mathew, 2016; Bieker, Slupphaug and Johansen, 2006)
	10	Kanban Application	Increase, Decrease and Unsettled	Normal, High and Low	Low and High Variation	Positive and Negative	(Agarwal, Sharma and Mathew, 2016; Garbie, 2011; Sakhardande, 2011)
	11	Reduced design cycle time and Lead time	Unsettled and Decrease	Normal and Low	Low and High Variation	Negative	(Bieker, Slupphaug and Johansen, 2006; Menhat and Yusuf, 2018; Röthlisberger, 2005)
	12	Reduction in Manpower	Decrease	Low	Low Variation	Negative	(Röthlisberger, 2005)
<b>Alliances</b>	13	Contractual relationships with other operating companies for sharing materials	Increase, Decrease and Unsettled	Normal, High and Low	Low and High Variation	Positive and Negative	(Dauda and Yusuf, 2004; EY, 2015)
	14	Execute the field's overall development	Increase	Normal and High	Low Variation	Positive	(Ernst and Steinhubl, 1997; EY, 2015)
	15	Collaborative bidding and rate negotiations with current contractors	Unsettled and Decrease	Normal and Low	Low and High Variation	Negative	(Chima, 2007; Röthlisberger, 2005)
<b>Wide Technology for Data Sharing</b>	16	Sharing information on reserves, innovations and operational's cases among companies of the sector	Increase, Decrease and Unsettled	Normal, High and Low	Low and High Variation	Positive	(Chima, 2007; Osinerg, 2005)
	17	Sharing Information into the company to integrate the production operations	Increase, Decrease and Unsettled	Normal, High and Low	Low and High Variation	Positive and Negative	(Oracle, 2011; Olinto, Oliveira and Rocha, 2018)
	18	Cross-channel Coordination	Increase and Unsettled	Normal and High	Low and High Variation	Positive and Negative	(Chima, 2007; Röthlisberger, 2005)
<b>Operational Innovation Technology</b>	19	Production Optimisation and changing the nature of the work	Increase	Normal and High	Low Variation	Positive	(Agility.com, 2017; Bieker, Slupphaug and Johansen, 2006; Shuen, Feiler and Teece, 2014)
	20	Early supplier involvement in product technology	Increase and Unsettled	Normal and High	Low and High Variation	Positive and Negative	(Dauda and Yusuf, 2004; Olinto, Oliveira and Rocha, 2018)
	21	Engineer-to-order for tools and equipment	Increase	Normal and High	Low Variation	Positive	(Cibir and Grant, 1996; Dauda and Yusuf, 2004; Shuen, Feiler and Teece, 2014)

## 5. Analysis and Results

### 5.1. Calculation of Total Production Cost Function and its variables

The historical data is organised according to Appendix 2 to be imported in the EViews software, using the Cobb-Douglas type production cost function (Equation 4), defined in chapter 4.1.1 and subject to restriction(5).

R-squared and F-statistic are considered for the result analysis obtained in Figure 12.



Equation: UNTITLED Workfile: FINAL\_BASE\_DISSERTATION:...

View Proc Object Print Name Freeze Estimate Forecast Stats Resids

Dependent Variable: LN\_PC\_  
 Method: Least Squares (Gauss-Newton / Marquardt steps)  
 Date: 07/15/19 Time: 17:01  
 Sample (adjusted): 1 20  
 Included observations: 20 after adjustments  
 LN\_PC\_=C(1)+C(2)\*LN\_Q\_+C(3)\*LN\_W1\_+C(4)\*LN\_W2\_+(1-C(3)-C(4))\*LN\_W3\_

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-15.46164	0.544326	-28.40513	0.0000
C(2)	1.055201	0.035066	30.09143	0.0000
C(3)	0.011224	0.000720	15.59515	0.0000
C(4)	0.935205	0.003978	235.1127	0.0000

R-squared	0.999756	Mean dependent var	18.56573
Adjusted R-squared	0.999710	S.D. dependent var	0.740580
S.E. of regression	0.012607	Akaike info criterion	-5.732330
Sum squared resid	0.002543	Schwarz criterion	-5.533183
Log likelihood	61.32330	Hannan-Quinn criter.	-5.693454
F-statistic	21850.99	Durbin-Watson stat	1.755366
Prob(F-statistic)	0.000000		

Figure 12: EViews result of Total Production Cost

According to the results expressed in Figure 12,  $R^2$  determines that 99.97% of the variation of the Production Cost is explained by the variation of the Production Level (Q) and of the costs  $W_1, W_2$  and  $W_3$ . Similarly, the critical value  $p(F\text{-statistic})$  indicates that the model is significant since its probability is less than 0.05. Therefore, the variables  $Q, W_1, W_2$ , and  $W_3$  have a significant effect on the Total production cost (PC), which function is expressed by the equation(21) (Lind, Marchal and Mason, 2004).

$$\ln(PC_t) = 15.46164 + 1.055201\ln(Q_t) + 0.011224\ln(W_{1t}) + 0.935205\ln(W_{2t}) + 0.053571\ln(W_{3t}) \quad (21)$$

Likewise, to simulate the scenarios proposed in chapter 4.1.2., the historical data of the variables indicated in table 7 have been calculated in Excel, obtaining the results shown in the same table. As equal for the Cost Production Function, the analysis result is carried out under the indicators  $R^2$ , p-value and F-Critical Value (Lind, Marchal and Mason, 2004).

Table 7: Results of Crude Oil Price, Production Level and Total Index (Lind, Marchal and Mason, 2004)

Linear Regression - Variable (Y)	Variable (X)		Multiple Correlation Coef.	$R^2$	F - Critical Value	Elasticity	P-value	Coef.
Crudel Oil Price (COP)	WTI	Brent	1	1	7.50E-269	$\alpha_0$	4.97E-244	-2.65846
						$\alpha_1$	1.39E-235	0.074901
						$\alpha_2$	2.69E-255	0.9376
Production Level (Q)	COP		0.9841	0.9666	5.96E-15	$\gamma_0$	1.62E-20	2937759.42
						$\gamma_1$	5.96E-15	21201.3004
Total Index	COP		0.9862	0.9726	1.61E-15	$\theta_0$	1.61E-08	97.7807
						$\theta_1$	1.61E-15	3.812

As it can be seen in Table 7, the p-value of all the variables and the critical value p(F-statistic) of each linear regression model are less than 0.05. These observations indicate that for each linear regression model, the X variable is statistically significant for the Y variable (Lind, Marchal and Mason, 2004). Therefore, replacing the coefficients found with Excel in equations (21),(22) and (23), each model will be expressed as follows:

$$COP_t = -2.65846 + 0.074901 * WTI_t + 0.9376 * Brent_t \quad (21)$$

$$Q_t = 2937759.42 + 21201.3004 * COP_t \quad (22)$$

$$Total\ Index_t = 97.7807 + 3.812 * COP_t \quad (23)$$

## 5.2. Simulation Results

### Calculation of $COP_t$ , $Q_t$ and $Total.Index_t$

For the calculation of these values, the models indicated in the red box of the Figure 13 are applied.

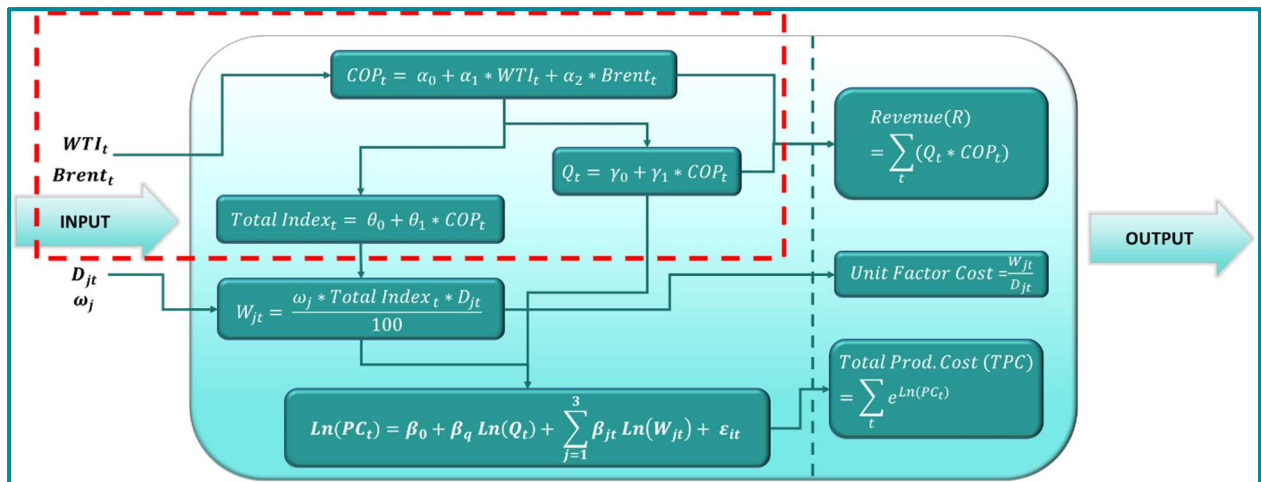


Figure 13: Calculation of  $COP_t$ ,  $Q_t$  and  $Total.Index_t$  (Lewis and Orav, 1989; Lewis-Beck, Bryman and Liao, 2004).

Based on the crude oil price fluctuation behaviour explained in 4.2.1., the WTI and Brent values indicated in Appendix 3 are determined. Applying these values in equation (21), the COP for the period 2019 to 2028 is determined, in the Figure 14:

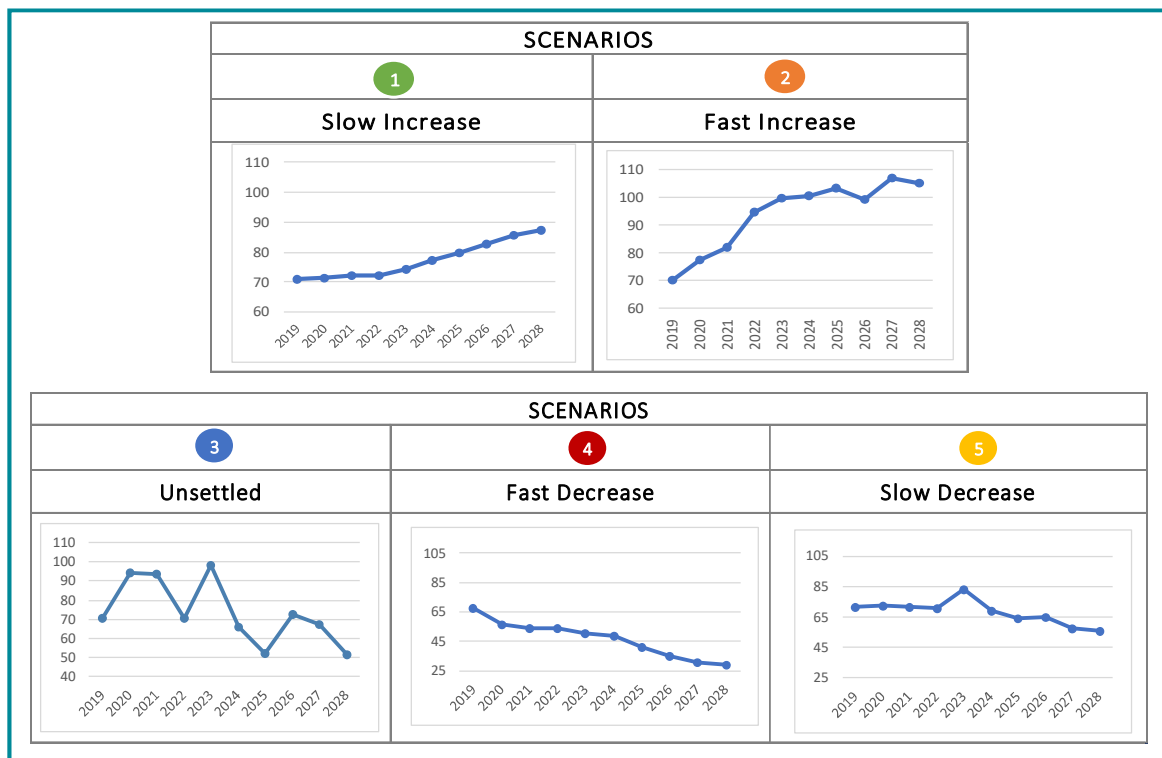


Figure 14: Scenarios of Crude Oil Price Fluctuation (BBC, 2016, ECB, 2015, EIA, 2019a)

The  $COP_t$  is applied in equations (22) and (23) in order to calculate the production level ( $Q$ ) as well as the Total Index in each period. The results are shown in Tables 8 and 9, respectively. The  $Total.Index_t$  is used to calculate the Unit Costs of Productive

## Factors with equation (10).

Table 8: Production Level Results per scenario.

Year	SCENARIO 1		SCENARIO 2		SCENARIO 3		SCENARIO 4		SCENARIO 5	
	Q	COP	Q	COP	Q	COP	Q	COP	Q	COP
2019	4,445,415	71.11	4,426,997	70.24	4,426,997	70.24	4,367,450	67.43	4,457,867	71.70
2020	4,448,504	71.26	4,581,753	77.54	4,935,186	94.21	4,124,454	55.97	4,477,464	72.62
2021	4,474,111	72.46	4,678,959	82.13	4,922,863	93.63	4,076,973	53.73	4,450,235	71.34
2022	4,472,271	72.38	4,943,142	94.59	4,431,075	70.44	4,074,009	53.59	4,434,894	70.62
2023	4,510,813	74.20	5,046,082	99.44	5,022,853	98.35	3,998,149	50.02	4,695,455	82.91
2024	4,577,612	77.35	5,068,146	100.48	4,337,312	66.01	3,969,428	48.66	4,406,433	69.27
2025	4,629,818	79.81	5,130,183	103.41	4,041,725	52.07	3,812,209	41.25	4,295,968	64.06
2026	4,695,455	82.91	5,034,486	98.90	4,470,831	72.31	3,675,814	34.81	4,307,605	64.61
2027	4,751,389	85.54	5,199,862	106.70	4,357,190	66.95	3,595,016	31.00	4,163,996	57.84
2028	4,792,338	87.47	5,163,412	104.98	4,021,847	51.13	3,561,400	29.42	4,126,730	56.08

Table 9: Total Index Results per scenario

Year	SCENARIO 1		SCENARIO 2		SCENARIO 3		SCENARIO 4		SCENARIO 5	
	Total Index	COP	Total Index	COP	Total Index	COP	Total Index	COP	Total Index	COP
2019	368.86	71.11	365.54	70.24	365.54	70.24	354.84	67.43	371.09	71.70
2020	369.41	71.26	393.37	77.54	456.92	94.21	311.15	55.97	374.62	72.62
2021	374.01	72.46	410.85	82.13	454.70	93.63	302.61	53.73	369.72	71.34
2022	373.68	72.38	458.35	94.59	366.28	70.44	302.08	53.59	366.96	70.62
2023	380.61	74.20	476.85	99.44	472.68	98.35	288.44	50.02	413.81	82.91
2024	392.62	77.35	480.82	100.48	349.42	66.01	283.27	48.66	361.85	69.27
2025	402.01	79.81	491.98	103.41	296.27	52.07	255.01	41.25	341.98	64.06
2026	413.81	82.91	474.77	98.90	373.42	72.31	230.48	34.81	344.08	64.61
2027	423.87	85.54	504.50	106.70	352.99	66.95	215.95	31.00	318.26	57.84
2028	431.23	87.47	497.95	104.98	292.70	51.13	209.91	29.42	311.56	56.08

**Calculation of  $D_{jt}$  and  $W_{jt}$** 

To find these values, the model indicated in the red box of Figure 15 is used.

The COP and Q results found in the previous section are applied to equations (13) and (14), obtaining the results shown for scenario 1 in Table 10. The results for scenarios 2 to 5 are detailed in Appendix 4.

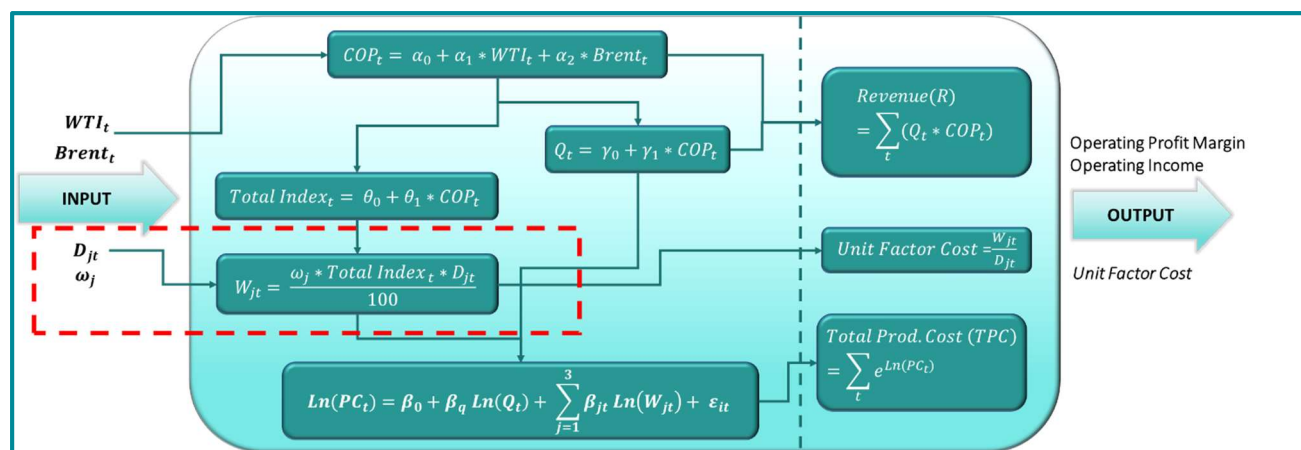


Figure 15: Calculation of  $D_{jt}$  and  $W_{jt}$  (Lewis and Orav, 1989; Lewis-Beck, Bryman and Liao, 2004).

Table 10: Results of Drilled, Producing and Injection wells for Scenario 1 (Carvajal, 2012, CNPC, 2019; Ego and Orihuela, 2014; Osinerg, 2005; PERUPETRO, 2019; Tamayo et al., 2015).

	SCENARIO 1						
	Production Level	Crude Oil Price	Production Level per Well	Producing Wells	Drilled Producing Wells	Injection Wells	Drilled Injection Wells
Year	Q	COP	PL	$D_2$	$D_1$	$D_{32}$	$D_{31}$
2019	4,445,415	71.11	1412	3149	50	85	0
2020	4,448,504	71.26	1403	3172	50	86	1
2021	4,474,111	72.46	1321	3387	86	92	6
2022	4,472,271	72.38	1365	3277	67	89	0
2023	4,510,813	74.20	1326	3402	60	92	3
2024	4,577,612	77.35	1339	3419	70	92	0
2025	4,629,818	79.81	1369	3382	73	91	0
2026	4,695,455	82.91	1371	3425	70	93	2
2027	4,751,389	85.54	1372	3464	70	94	1
2028	4,792,338	87.47	1327	3612	71	98	4

The calculation of the Development cost and Lease Equipment cost for Primary Recovery ( $W_{1t}$ ) is comprised by unit cost of each operation as is shown in Table 11. In this table, the Secondary Data  $\omega_1$  is normalised to the Drilled Wells ( $D_1$ ) and the Total.Index per year is calculated in Tables 10 and 9, respectively.



Table 11: Unit Cost by Operative Function of Development and Lease Equipment cost for Primary Recovery (Ego and Orihuela, 2014; EIA, 2010; EIA, 2019b).

SECONDARY DATA		SCENARIO 1									
New Producing Wells	10	50	50	86	67	60	70	73	70	70	71
Total Index	100	368.86	369.41	374.01	373.68	380.61	392.62	402.01	413.81	423.87	431.23
Component	BASE 1994	MM									
		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Development and Producing Equipment:</b>											
Casing and Tubing	113,200	2.1	2.1	3.6	2.8	2.6	3.1	3.3	3.3	3.4	3.5
Bits	78,800	1.5	1.5	2.5	2.0	1.8	2.2	2.3	2.3	2.3	2.4
Pumps	98,900	1.8	1.8	3.2	2.5	2.3	2.7	2.9	2.9	2.9	3.0
<b>Subtotal or Index</b>	<b>290,900</b>	<b>5</b>	<b>5</b>	<b>9</b>	<b>7</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>8</b>	<b>9</b>	<b>9</b>
<b>Development Services:</b>											
Wireline Services	77,200	1.4	1.4	2.5	1.9	1.8	2.1	2.3	2.2	2.3	2.4
Drilling Rig	308,510	5.7	5.7	9.9	7.7	7.0	8.5	9.1	8.9	9.2	9.4
Cementing	227,000	4.2	4.2	7.3	5.7	5.2	6.2	6.7	6.6	6.7	7.0
Drilling Fluids	196,150	3.6	3.6	6.3	4.9	4.5	5.4	5.8	5.7	5.8	6.0
Well Testing	68,500	1.3	1.3	2.2	1.7	1.6	1.9	2.0	2.0	2.0	2.1
Stimulation (Hydraulic Fracturing)	234,200	4.3	4.3	7.5	5.9	5.3	6.4	6.9	6.8	6.9	7.2
Facilities (Platforms, roads...)	112,800	2.1	2.1	3.6	2.8	2.6	3.1	3.3	3.3	3.3	3.5
<b>Subtotal or Index</b>	<b>1,224,360</b>	<b>23</b>	<b>23</b>	<b>39</b>	<b>31</b>	<b>28</b>	<b>34</b>	<b>36</b>	<b>35</b>	<b>36</b>	<b>37</b>
<b>Gathering System:</b>											
Flowlines	48,800	0.9	0.9	1.6	1.2	1.1	1.3	1.4	1.4	1.4	1.5
Manifold	18,510	0.3	0.3	0.6	0.5	0.4	0.5	0.5	0.5	0.5	0.6
<b>Subtotal or Index</b>	<b>67,310</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>
<b>Lease Equipment:</b>											
Producing Separator	11,110	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Test Separator	12,910	0.2	0.2	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Storage Tanks	36,280	0.7	0.7	1.2	0.9	0.8	1.0	1.1	1.1	1.1	1.1
Disposal System	27,120	0.5	0.5	0.9	0.7	0.6	0.7	0.8	0.8	0.8	0.8
LACT Unit	12,620	0.2	0.2	0.4	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Electrification	67,400	1.2	1.2	2.2	1.7	1.5	1.9	2.0	2.0	2.0	2.1
<b>Subtotal or Index</b>	<b>167,440</b>	<b>3.1</b>	<b>3.1</b>	<b>5.4</b>	<b>4.2</b>	<b>3.8</b>	<b>4.6</b>	<b>4.9</b>	<b>4.9</b>	<b>5.0</b>	<b>5.1</b>
<b>TOTAL</b>	<b>1,750,010</b>	<b>32.3</b>	<b>32.3</b>	<b>56.3</b>	<b>43.8</b>	<b>40.0</b>	<b>48.1</b>	<b>51.4</b>	<b>50.7</b>	<b>51.9</b>	<b>53.6</b>

Similarly, the Annual Operating Costs for Primary Recovery ( $W_{2t}$ ) are calculated, as well as the Lease Equipment Cost and Operation Cost for Secondary Recovery ( $W_{3t}$ ), which results are shown in Tables 12 and 13.

For the calculation of  $W_{2t}$ , the Secondary Data  $\omega_2$  is normalised based on the producing wells ( $D_2$ ) and Total.Index in each year, calculated in Tables 10 and 9, respectively.

For the calculation of  $W_{3t}$ , the Secondary Data  $\omega_3$  is normalised based on the drilled injection Wells ( $D_{31}$ ) and the active injection wells in each year ( $D_{32}$ ), which results are shown in Tables 10 and 9.

The results of the other scenarios are shown in Appendix 5, 6 y 7.



Table 13: Unit Cost by Operative Function of Annual Operating Costs for Primary Recovery (Ego and Orihuela, 2014; EIA, 2010; EIA, 2019b).

SECONDARY DATA		SCENARIO 1										
Producing Wells		3149	3172	3387	3277	3402	3419	3382	3425	3464	3612	
INDEX		100	368.86	369.41	374.01	373.68	380.61	392.62	402.01	413.81	423.87	431.23
BASE		MM										
Component	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	
<b>Normal Daily Expense:</b>												
Supervision and Overhead..	21,900	10.2	10.3	11.1	10.7	11.3	11.8	11.9	12.4	12.9	13.6	
Labor (pumper).....	26,500	12.3	12.4	13.4	13.0	13.7	14.2	14.4	15.0	15.6	16.5	
Auto Usage.....	6,800	3.2	3.2	3.4	3.3	3.5	3.7	3.7	3.9	4.0	4.2	
Chemicals.....	3,700	1.7	1.7	1.9	1.8	1.9	2.0	2.0	2.1	2.2	2.3	
Fuel, Power & Water.....	74,700	34.7	35.0	37.9	36.6	38.7	40.1	40.6	42.3	43.9	46.5	
Operative Supplies.....	1,800	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	
<b>Subtotal or Index.....</b>	<b>135,400</b>	<b>62.9</b>	<b>63.5</b>	<b>68.6</b>	<b>66.3</b>	<b>70.1</b>	<b>72.7</b>	<b>73.6</b>	<b>76.8</b>	<b>79.5</b>	<b>84.4</b>	
<b>Surface Maintenance, Repair &amp; Services:</b>												
Labor (roustabout).....	10,800	5.0	5.1	5.5	5.3	5.6	5.8	5.9	6.1	6.3	6.7	
Supplies & Services.....	7,000	3.3	3.3	3.5	3.4	3.6	3.8	3.8	4.0	4.1	4.4	
Equipment Usage.....	3,300	1.5	1.5	1.7	1.6	1.7	1.8	1.8	1.9	1.9	2.1	
<b>Subtotal or Index.....</b>	<b>21,100</b>	<b>9.8</b>	<b>9.9</b>	<b>10.7</b>	<b>10.3</b>	<b>10.9</b>	<b>11.3</b>	<b>11.5</b>	<b>12.0</b>	<b>12.4</b>	<b>13.1</b>	
<b>Subsurface Maintenance, Repair &amp; Services:</b>												
Workover Rig Services	17,100	7.9	8.0	8.7	8.4	8.9	9.2	9.3	9.7	10.0	10.7	
Remedial Services	2,500	1.2	1.2	1.3	1.2	1.3	1.3	1.4	1.4	1.5	1.6	
Equipment Repair	11,300	5.3	5.3	5.7	5.5	5.9	6.1	6.1	6.4	6.6	7.0	
Other	500	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	
<b>Subtotal or Index.....</b>	<b>31,400</b>	<b>14.6</b>	<b>14.7</b>	<b>15.9</b>	<b>15.4</b>	<b>16.3</b>	<b>16.9</b>	<b>17.1</b>	<b>17.8</b>	<b>18.4</b>	<b>19.6</b>	
<b>TOTAL</b>	<b>187,900.0</b>	<b>87.3</b>	<b>88.1</b>	<b>95.2</b>	<b>92.0</b>	<b>97.3</b>	<b>100.9</b>	<b>102.2</b>	<b>106.5</b>	<b>110.4</b>	<b>117.1</b>	

Table 12: Unit Cost by Operative Function of Drilled injection Wells and the active injection wells for Secondary Recovery(Ego and Orihuela, 2014; EIA, 2010; EIA, 2019b).

SECONDARY DATA		SCENARIO 1										
Drilled Injection Wells		0	1	6	0	3	0	0	2	1	4	
INDEX		100	368.86	369.41	374.01	373.68	380.61	392.62	402.01	413.81	423.87	431.23
BASE		MM										
Component	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	
<b>Injection Equipment:</b>												
Supply Wells.....	127900	0.00	0.04	0.26	0.00	0.13	0.00	0.00	0.10	0.05	0.20	
Plant.....	96300	0.00	0.03	0.20	0.00	0.10	0.00	0.00	0.07	0.04	0.15	
Distribution Lines.....	76200	0.00	0.03	0.16	0.00	0.08	0.00	0.00	0.06	0.03	0.12	
Header.....	48700	0.00	0.02	0.10	0.00	0.05	0.00	0.00	0.04	0.02	0.08	
Electrical Service.....	87600	0.00	0.03	0.18	0.00	0.09	0.00	0.00	0.07	0.03	0.14	
<b>Subtotal or Index..</b>	<b>436,700</b>	<b>-</b>	<b>0</b>	<b>1</b>	<b>-</b>	<b>0</b>	<b>-</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>1</b>	
<b>Producing Equipment:</b>												
Tubing Replacement.....	88700	0.00	0.03	0.18	0.00	0.09	0.00	0.00	0.07	0.03	0.14	
Rods & Pumps.....	59000	0.00	0.02	0.12	0.00	0.06	0.00	0.00	0.04	0.02	0.09	
Pumping Equipment.....	284100	0.00	0.10	0.58	0.00	0.29	0.00	0.00	0.21	0.11	0.45	
<b>Subtotal or Index..</b>	<b>431,800</b>	<b>-</b>	<b>0.15</b>	<b>0.88</b>	<b>0.00</b>	<b>0.45</b>	<b>0.00</b>	<b>0.00</b>	<b>0.32</b>	<b>0.17</b>	<b>0.68</b>	
<b>Injection Wells</b>												
<b>Normal Daily Expense:</b>	<b>11</b>	<b>85</b>	<b>86</b>	<b>92</b>	<b>89</b>	<b>92</b>	<b>92</b>	<b>91</b>	<b>93</b>	<b>94</b>	<b>98</b>	
Supervision and Overhead..	47700	1.36	1.38	1.49	1.44	1.52	1.57	1.59	1.67	1.73	1.83	
Labor (pumper).....	51800	1.48	1.50	1.62	1.57	1.65	1.70	1.72	1.81	1.88	1.99	
Chemicals.....	6700	0.19	0.19	0.21	0.20	0.21	0.22	0.22	0.23	0.24	0.26	
Fuel, Power & Water.....	120000	3.42	3.47	3.75	3.63	3.82	3.94	3.99	4.20	4.35	4.61	
Operative Supplies.....	6400	0.18	0.18	0.20	0.19	0.20	0.21	0.21	0.22	0.23	0.25	
<b>Subtotal or Index.....</b>	<b>232,600</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>9</b>	
<b>Surface Maintenance, Repair &amp; Services:</b>												
Labor (roustabout).....	26700	0.76	0.77	0.84	0.81	0.85	0.88	0.89	0.93	0.97	1.03	
Supplies & Services.....	37600	1.07	1.09	1.18	1.14	1.20	1.23	1.25	1.32	1.36	1.44	
Equipment Usage.....	14400	0.41	0.42	0.45	0.44	0.46	0.47	0.48	0.50	0.52	0.55	
Other.....	4400	0.13	0.13	0.14	0.13	0.14	0.14	0.15	0.15	0.16	0.17	
<b>Subtotal or Index.....</b>	<b>83,100</b>	<b>2.37</b>	<b>2.40</b>	<b>2.60</b>	<b>2.51</b>	<b>2.65</b>	<b>2.73</b>	<b>2.76</b>	<b>2.91</b>	<b>3.01</b>	<b>3.19</b>	
<b>Subsurface Maintenance, Repair &amp; Services:</b>												
Workover Rig Services.....	46400	1.32	1.34	1.45	1.40	1.48	1.52	1.54	1.62	1.68	1.78	
Remedial Services.....	13900	0.40	0.40	0.43	0.42	0.44	0.46	0.46	0.49	0.50	0.53	
Equipment Repair.....	11200	0.32	0.32	0.35	0.34	0.36	0.37	0.37	0.39	0.41	0.43	
Other.....	9100	0.26	0.26	0.28	0.28	0.29	0.30	0.30	0.32	0.33	0.35	
<b>Subtotal or Index.....</b>	<b>80,600</b>	<b>2.30</b>	<b>2.33</b>	<b>2.52</b>	<b>2.44</b>	<b>2.57</b>	<b>2.65</b>	<b>2.68</b>	<b>2.82</b>	<b>2.92</b>	<b>3.10</b>	
<b>TOTAL</b>	<b>1,264,800</b>	<b>11</b>	<b>12</b>	<b>14</b>	<b>12</b>	<b>14</b>	<b>13</b>	<b>13</b>	<b>15</b>	<b>15</b>	<b>17</b>	

### Calculation of $PC_t$

To calculate these values, the models described in the red box of the Figure 16 are applied.

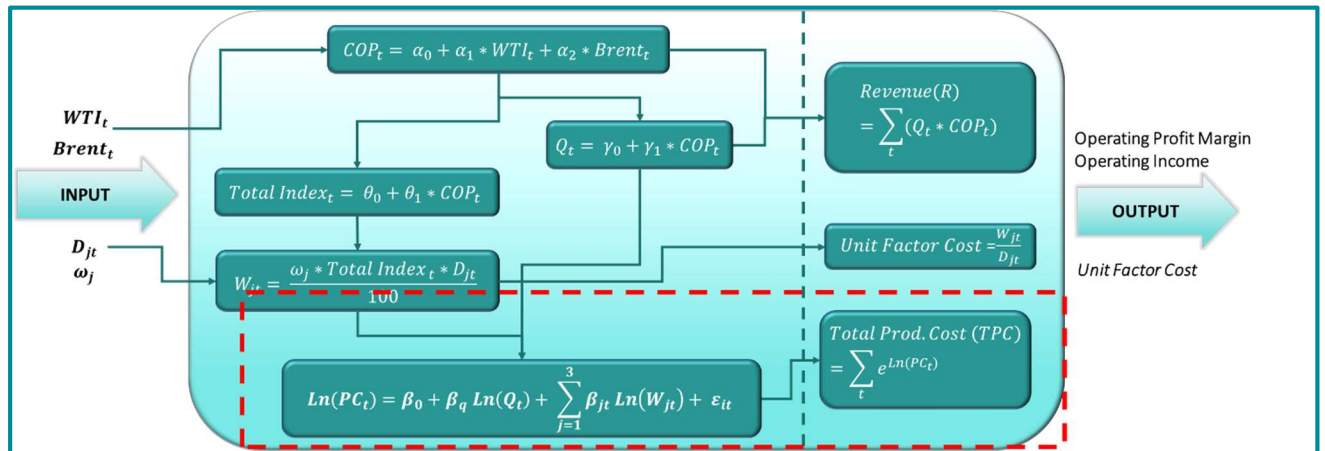


Figure 16: Calculation of  $PC_t$  (Lewis and Orav, 1989; Lewis-Beck, Bryman and Liao, 2004).

The total sum of the previous unit costs calculated gives the global values of the factors  $W_1, W_2$  and  $W_3$ , that together with the production level results ( $Q_t$ ) of the table 8 are applied in equation (21).

The results calculated with Excel for scenario 1 are shown in Table 14. The other scenarios are detailed in Appendix 8.

Table 14: Total Production Cost for Scenario 1 (Ego and Orihuela, 2014; Morocho, 2016).

		$\beta_0$	$\beta_q$	$\beta_1$	$\beta_2$	$\beta_3$					
		-15.46164	1.055201	0.011224	0.935205	0.053571					
<b>SCENARIO 1</b>											
Year	Q(t) [bbl]	W1	W2	W3	LN(q)	LN(W1)	LN(W2)	LN(W3)	ln(PC)	PC	
2019	4,445,415	32,275,014	87,300,219	11,295,520	15.31	17.29	18.28	16.24	18.85	154,371,383	
2020	4,448,504	32,323,618	88,070,282	11,737,285	15.31	17.29	18.29	16.28	18.87	156,081,701	
2021	4,474,111	56,289,535	95,211,772	14,168,561	15.31	17.85	18.37	16.47	18.96	171,685,397	
2022	4,472,271	43,814,687	92,038,089	11,981,902	15.31	17.60	18.34	16.30	18.92	164,306,430	
2023	4,510,813	39,964,665	97,320,756	13,517,010	15.32	17.50	18.39	16.42	18.98	175,634,871	
2024	4,577,612	48,096,722	100,893,406	13,013,560	15.34	17.69	18.43	16.38	19.03	184,505,734	
2025	4,629,818	51,357,145	102,187,519	13,179,844	15.35	17.75	18.44	16.39	19.06	189,233,572	
2026	4,695,455	50,692,256	106,524,719	14,518,367	15.36	17.74	18.48	16.49	19.12	200,686,937	
2027	4,751,389	51,924,242	110,356,076	14,689,255	15.37	17.77	18.52	16.50	19.16	210,226,167	
2028	4,792,338	53,580,807	117,069,802	16,587,276	15.38	17.80	18.58	16.62	19.23	225,728,467	
										<b>1,832,460,658</b>	

### 5.3. Calculation of Profit Margin Ratios and Definition of parameters for simulation scenarios

After obtaining the results of the Total Production Cost, the Revenue is calculated in Excel, as indicated in the Red box of Figure 17.

The Unit Factor Cost is also indicated in this figure, which is obtained from the results calculated in Appendix 5, 6 and 7.

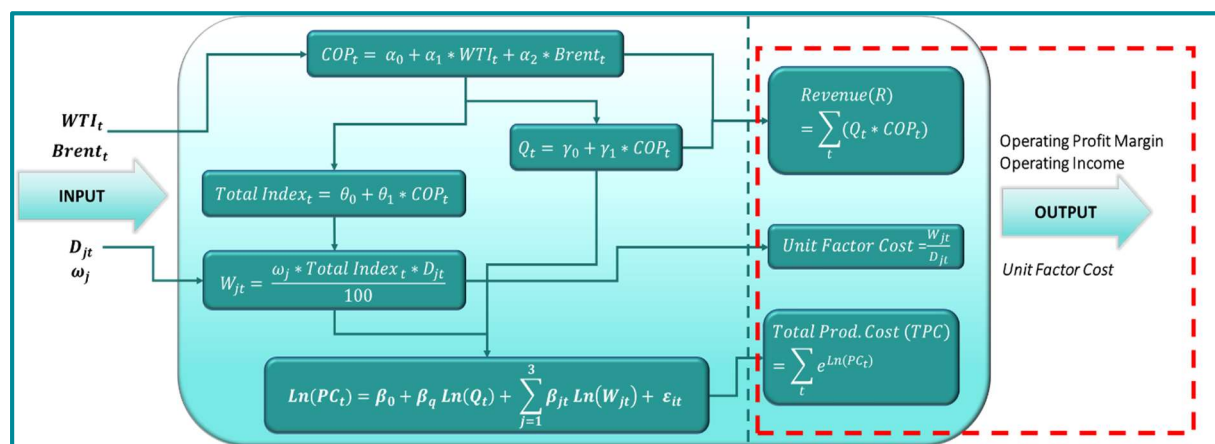


Figure 17: Calculation of the Simulation System Output (Lewis and Orav, 1989; Lewis-Beck, Bryman and Liao, 2004).

The Operating Profit Margin, Operation Income per year and Operating Income Variation per year are calculated. These results are shown in Figure 19 using the equations (16),(17),(18) and (19). The calculation detail is in Appendix 7.

Comparing the Operating Profit Margin of the five scenarios (See Figure 18), it is observed that in all cases would have greater business performance for the company respect to the historical data. However, the scenario 2 has a better operating profit margin despite having the highest production costs. Due to the similarity in Operating Profit Margin of scenarios 1,3,4,5, it would be correct to assert that the scenario 1 is the optimal one, because of the greater amount of Operating Income generated in the 10 years.

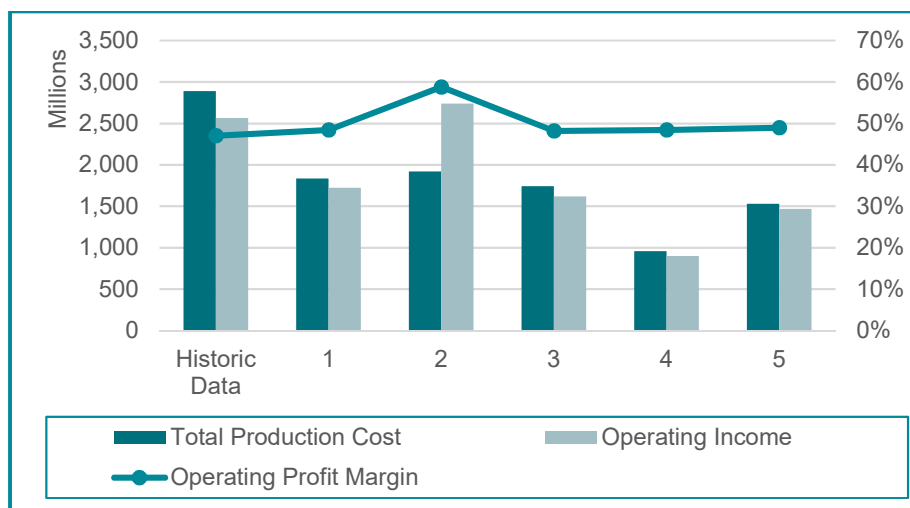


Figure 18: Results of Simulation System Output

The Operating Income Variation is calculated in Appendix 9 since the objective of this section is not to find the best scenario, but to analyse each of them. The graphs of this variation are found in Figure 19, where it is observed that Scenario 3 presents a behaviour with a greater variability and with a positive tendency, followed by scenario 5, which also has the same tendency. Likewise, it can be said that scenario 1 is the most stable and with a positive tendency, as well.

To determine in a more objective way the degree of variability such as the Operating Income tendency, the parameters description in Table 4 are applied in the results of the Appendix 7 using Excel. The final quantitative parameters are shown in the Table 15.

Table 15: Quantitative Parameter of the Case study Final Results.

Metric Analysis	Calculation Type	Scenario 1	Scenario 2	Scenario 3	Senario 4	Scenario 5
Crude Oil Price Tendency	Median	75.77	99.17	70.34	49.34	69.94
Operating Income Tendency	Median	4.05%	7.10%	-9.24%	-12.06%	-7.51%
Operating Income Variability	Variance	0.16%	0.92%	13.33%	0.76%	1.19%

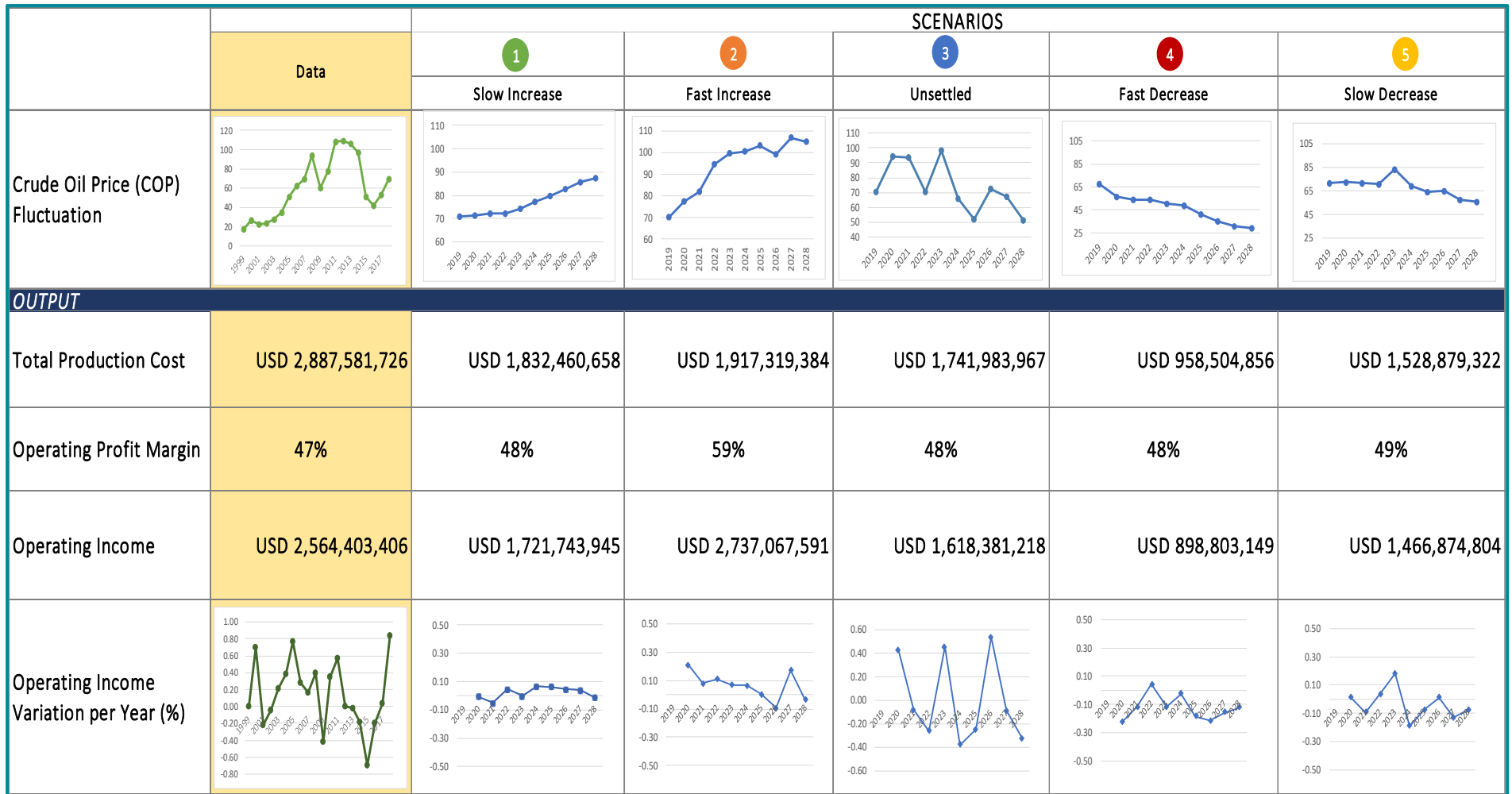


Figure 19: Results of Simulation System Output

Although, in the previous visual analysis, it was said that scenario 3 and 5 had a positive trend in the Operating Income Variation, the values calculated in Table 15 show that both have a negative tendency. In addition, Scenario 1 is the most stable as previously stated.

The Crude Oil Price Tendency was also calculated in the same table in order to compare and define these values with the linguistic labelling indicated in Table 4, as is shown in Table 16.

Table 16: Linguistic Terms of Quantitative Analysis Output for the Case study

Classification Type	Scenario 1	Scenario 2	Scenario 3	Senario 4	Scenario 5
Crude Oil Price Tendency	Normal	High	Normal	Low	Low
Operating Income Variability	Low Variation	Low Variation	High Variation	Low Variation	Low Variation
Operating Income Tendency	Positive	Positive	Negative	Negative	Negative

In summary, the final Linguistic terms for each scenario is the following:

Table 17: Linguistic terms by scenario as Input of the Qualitative Analysis for the Case study.

	SCENARIOS				
	1	2	3	4	5
Crude Oil Price Behaviour	Slow Increase	Fast Increase	Unsettled	Fast Decrease	Slow Decrease
Crude Oil Price Tendency	Normal	High	Normal	Low	Low
Operating Income Variability	Low Variation	Low Variation	High Variation	Low Variation	Low Variation
Operating Income Tendency	Positive	Positive	Negative	Negative	Negative

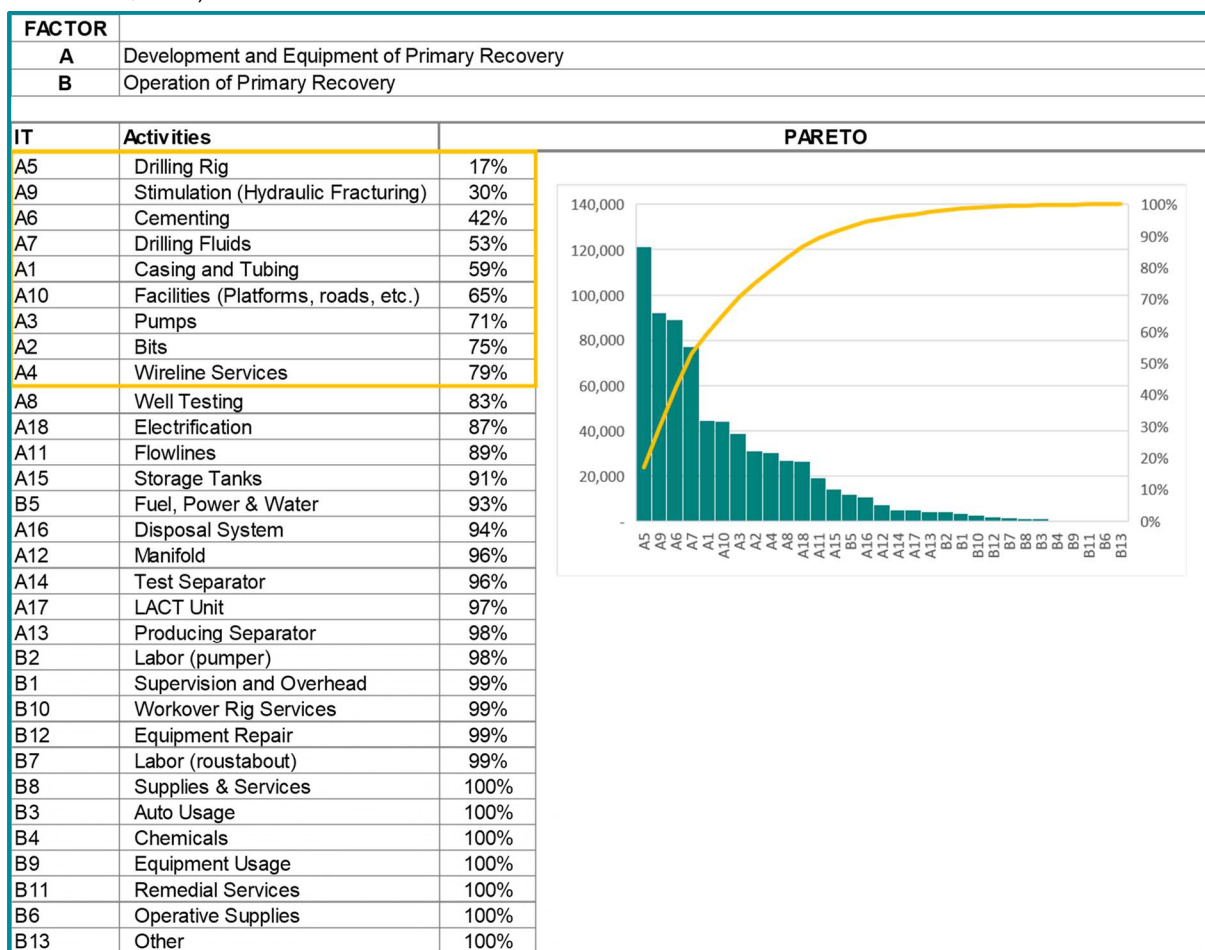
#### 5.4. Calculation of Operative Function Costs

In order to make a more precise and relevant analysis, the application of the Agility enablers will be suggested only in the most expensive operations. To do this, analysing the results shown in Figure 20, the primary recovery operation cost is the most significant factor of all scenarios, whose costs have a similar behaviour with the crude oil Price fluctuation.

On the other hand, the development and lease equipment cost of primary recovery is also relevant since if the cost per well is analysed. This represents 96% of the total cost. Therefore, all the activities of the Primary Recovery are selected and classified by unit cost. After that, the most significant operative functions are identified by Pareto Chart, as shown in Table 18 (Agarwal et al., 2016; Lind, Marchal and Mason, 2004).

The numerical detail of the stated analysis is found in Appendix 10:

Table 18: Pareto Chart for Unit Cost of Operative Functions (Agarwal, Sharma and Mathew, 2016; Lind, Marchal and Mason, 2004)



The analysis was performed for the five crude oil price fluctuation scenarios, which aggregate percentage is the same in each operation. Besides, it is observed in Table 18 that the 20% of the functions, indicated in the yellow box, account for 80% of the cost per well (Agarwal et al., 2016; Lind, Marchal and Mason, 2004). In consequence, the application suggestions of Agility enablers will be focused on the indicated operative functions.



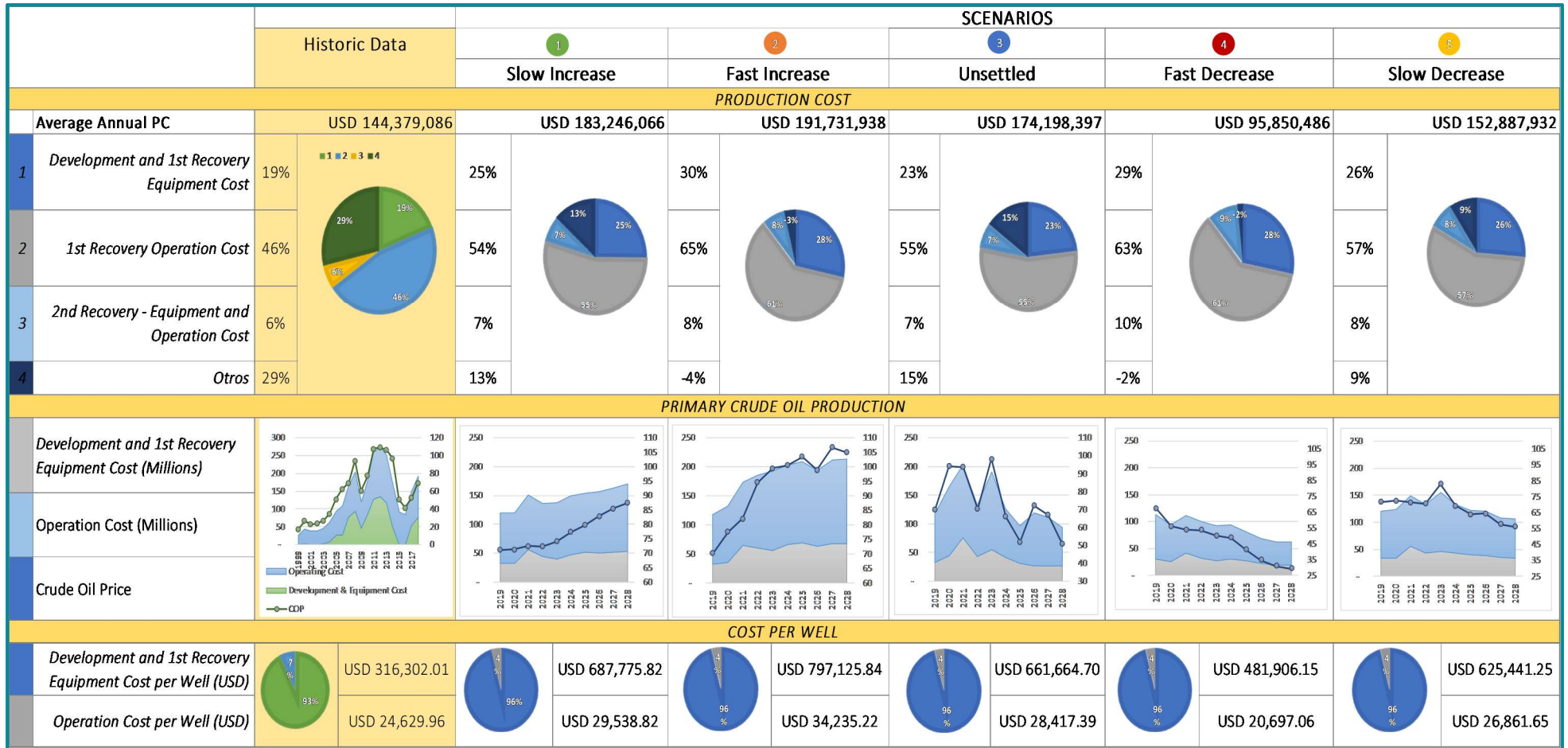


Figure 20: Production Cost Results



## 5.5. Application and Analysis of Agility Enablers in each Operative Function

After getting the linguistic terms of the quantitative results (Table 17), these ones are correlated with the Table 6 identified in the section 4.4., as is shown in Table 19.

Furthermore, the agility enablers (AE) by scenario are identified after analysing theoretical documents and applied to the operative functions determined in the section 5.4 which are related to the linguistic terms found as quantitative analysis result.

The following explains the application of each AE in Operative functions per scenario, with their respective summary table.

Table 19: Correlation between linguistic terms results of case study and agility enablers application in each scenario

	SCENARIOS				
	1	2	3	4	5
<b>Crude Oil Price Behaviour</b>	Slow Increase	Fast Increase	Unsettled	Fast Decrease	Slow Decrease
<b>Crude Oil Price Tendency</b>	Normal	High	Normal	Low	Low
<b>Operating Income Variability</b>	Low Variation	Low Variation	High Variation	Low Variation	Low Variation
<b>Operating Income Tendency</b>	Positive	Positive	Negative	Negative	Negative
<b>Vertical Integration</b>	Between Contractors				
<b>Outsourcing</b>	Supplier location close from oilfield				
	Optimal Pricing Strategy				
	Long term purchasing agreement				
<b>Customise Logistic Network</b>	3PL Contractor for Internal transportation and warehousing				
	Suppling materials in production line				
<b>Internal Operations</b>	Re-using or recycling old tools				
	Decentralisation of Operational decision making				
	Application of TPM and TQM				
	Kanban Application				
	Reduced design cycle time and Lead time				
<b>Alliance</b>	Contractual relationships with other operating companies for sharing materials				
	Execute the field's overall development				
	Collaborative bidding and rate negotiations with current contractors				
<b>Wide Technology for Data Sharing</b>	Sharing information on reserves, innovations and operational's cases among companies of the sector				
	Sharing Information into the company to integrate the production operations				
	Cross-channel Coordination				
<b>Operational Innovation Technology</b>	Production Optimisation and changing the nature of the work				
	Early supplier involvement in product technology				
	Engineer-to-order for tools and equipment				

### Vertical Integration

AE.1: Vertical Integration between Contractors (Al-Obaidan and Scully,1993; Chima, 2007; Cibin and Grant, 1996).

- Application Analysis: Developing and applying management technology to operational and strategic planning and resource allocation. For instance;
  1. Drilling Services should produce the Drill Pipes and/or should be the supplier of casing and tubing.
  2. Since the stimulation may be performed during workover and well completion, this service should be integrated as activity of one of those services.
  3. Cementing should provide the casing and tubing because of those are installed at the same time Cementing is being completed.
  4. Facilities should be developed by the same contractor of Drilling Services.
- Justification: Stable or high crude oil price tendency, because it implies the increase of fee in the contractor service cost.

Table 20: Application of AE.1 in Operative functions per scenario (Al-Obaidan and Scully, 1993; Chima, 2007; Cibin and Grant, 1996).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2	1 2	1 2		1 2	1 2		1 2	

### Outsourcing

AE.2: Supplier location close from oilfield (Dauda and Yusuf, 2004; Hussain et al., 2006).

- Application Analysis: Suppliers of casing, pumps, tubing and bits close to their operations.

Table 21: Application of AE.2 in Operative functions per scenario (Dauda and Yusuf, 2004; Hussain et al., 2006).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
				3 4 5		3 4 5	3 4 5	

AE.3: Optimal Pricing Strategy (Röthlisberger,2005).

- Application Analysis: Increased revenue through optimal pricing strategies. Most of the contractors can reduce their costs and, at the same time, the quality of the service or the material. Thus, it is necessary to analyse each scenario.
- Justification: Due to the fact that the priority is the cost reduction, this strategy fits in in the scenarios 4 and 5. In Scenario3, if this strategy is applied, it would be harmful since the service should be more responsive than cost efficient.

Table 22: Application of AE.3 in Operative functions per scenario (Röthlisberger, 2005)

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
4 5	4 5	4 5	4 5	4 5	4 5	4 5	4 5	4 5

AE.4: Long Term purchasing agreement (Agility.com, 2017; Dauda and Yusuf, 2004; Röthlisberger, 2005).

- Application Analysis: Long-term purchase agreement for casing, tubing, rods and pumps with a contractual relationship. In case of a project for two or three years, a long-term agreement should be more economic than one-year project. Therefore, bidding for services could help to reduce costs more than requesting a punctual service.
- Justification: For a lower oil price, it is better to ensure a long-term agreement for saving cost and ensuring low prices of services and goods.

Table 23: Application of AE.4 in Operative functions per scenario (Agility.com, 2017; Dauda and Yusuf, 2004; Röthlisberger, 2005).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
3 4 5	3 4 5	3 4 5	3 4 5	3 4 5	3 4 5	3 4 5	3 4 5	3 4 5

### Customise Logistic Network

AE.5: 3PL Contractor for Internal transportation and warehousing (Agarwal, Sharma and Mathew, 2016; Herrera, 2012).

- Application Analysis: 3PL contractors can act as a transportation analyst from supplier to oilfield. They should be in charge of the Warehouse Management, coordinating all material movements to a central distribution point for further transport to an oilfield operation.
- Justification: In normal and high crude oil price due to the profit margin affords the extra payment. Also, when there is a high variation of operating income among the years, it should be applied to respond to the production variability.

Table 24: Application of AE.5 in Operative functions per scenario (Agarwal, Sharma and Mathew, 2016; Herrera, 2012).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2 3				1 2 3	1 2 3	1 2 3	1 2 3	

AE.6: Suppling of materials in production line (Chima, 2007; Hussain et al., 2006).

- Application Analysis: Coordination between local service providers and internal workforce to supply the prepared casing and tubing in different batch drilling activity in where is taking place. There could be achieved savings of about 25% in procurement and installation costs.

Table 25: Application of AE.6 in Operative functions per scenario (Chima, 2007; Hussain et al., 2006).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
				1 2 3				

### Internal Operations

AE.7: Re-using or recycling old tools (Garbie and Al-Hosni, 2014).

- Application Analysis: Re-using or recycling for the old tools’ themes should be considered. Most of the equipment can be used again in different locations and some will require a re-dressing process to furnish the tool back to the process. For example, the fishing tools in Drilling and Well Testing.

Table 26: Application of AE.7 in Operative functions per scenario (Garbie and Al-Hosni, 2014)

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2 3 4 5								1 2 3 4 5

AE.8: Decentralisation of Operational decision making (Cibin and Grant, 1996).

- Application Analysis: Decentralisation with the desire to speed action by locating decision making as low in the organization as possible in order to respond the uncertainty in operation, avoiding stand-by cost and to encourage the entrepreneurship. This should be applied in the services where manpower is involved and, in which, the business organisation is hierarchical. For example, in Drilling and cementing service, which operations are related to the perforation.

Table 27: Application of AE.8 in Operative functions per scenario (Cibin and Grant, 1996).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
4 5		4 5						

AE.9: Application of TPM and TQM (Agarwal et al., 2016; Bieker et al., 2006).

- Application Analysis: Application of TQM<sup>7</sup> and TPM<sup>8</sup> are considered as the key operational activities of the quality management system to increase productivity of equipment with a modest investment in maintenance. In order to TPM to be effective, full support of the total workforce is required.
- The application in the upstream industry will optimise the productivity and quality; subsequently, reducing the overheads associated with the Development and Production process. These strategies would be applied in Mud Pumps, draw works, Drill Line, Prime mover (Motor), Blow Out Preventers, Casing Head and well head, Valves and Flow lines.

Table 28: Application of AE.9 in Operative functions per scenario (Agarwal et al., 2016; Bieker et al., 2006).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services

AE.10: Kanban Application (Agarwal et al., 2016); Garbie, 2011; Sakhardande, 2011).

- Application Analysis: Kanban can be a very effective lean tool in upstream to organise the flow of material, equipment to the right place at right time. Thereby, it reduces the wait time for the machinery and equipment to arrive which involve Drill pipes, Cement, bits and so on.

Table 29: Application of AE.10 in Operative functions per scenario (Agarwal et al., 2016; Garbie, 2011; Sakhardande, 2011).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services

AE.11: Reduced design cycle time and Lead time (Bieker et al., 2006; Röthlisberger, 2005).

- Application Analysis: Reduction of cycle time and overall lead-times for work processes.

<sup>7</sup> Total Quality Management  
<sup>8</sup> Total Productive Maintenance

Table 30: Application of AE.11 in Operative functions per scenario (Bieker et al., 2006; Röthlisberger, 2005).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
3 4 5	3 4 5	3 4 5	3 4 5					3 4 5

AE.12: Reduction in Manpower (Röthlisberger, 2005).

- Application Analysis: Only applied in work processes in case of emergency when crude oil price is lower in order to decrease the fix cost.

Table 31: Application of AE.12 in Operative functions per scenario (Röthlisberger, 2005).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
4 5	4 5	4 5	4 5		4 5			4 5

### Alliances

AE.13: Contractual relationships with other operating companies for sharing materials (Dauda and Yusuf, 2004; EY, 2015).

- Application Analysis: Contractual relationships with other operating companies. Due to the closeness of the oilfield in Peru Northwest, it can be possible to generate an agreement between operators to share drilling equipment or tools that are urgently needed.
- Justification: The enabler can be applied to any scenario but not in all the services, only the low cost ones and with materials supply. Having an agreement for bigger services can be risky and compromise the execution planned operation execution.

Table 32: Application of AE.13 in Operative functions per scenario (Dauda and Yusuf, 2004; EY, 2015).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
				1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

AE.14: Execute the field's overall development (Ernst and Steinhubl, 1997; EY, 2015).

- Application Analysis: Alliance of partners to plan and execute the field's overall development. Each partner stood to gain if the project came in under budget. The collective effort can result in savings of 20 to 25 percent and the production can be able to begin ahead of schedule.

Table 33: Application of AE.14 in Operative functions per scenario (Ernst and Steinhubl, 1997; EY, 2015).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2	1 2

AE.15: Collaborative bidding and rate negotiations with current contractors (Chima, 2007; Röthlisberger,2005).

- Application Analysis: Application in all the operative functions in case of steady or low prices.

Table 34: Application of AE.15 in Operative function per scenario (Chima, 2007; Röthlisberger, 2005).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
4 5 3	4 5 3	4 5 3	4 5 3	4 5 3	4 5 3	4 5 3	4 5 3	4 5 3

### Wide Technology for Data Sharing

AE.16: Sharing information on reserves, innovations and operational cases among companies of the sector (Chima, 2007; Osinerg, 2005).

- Application Analysis: The exploration cost and development cannot be ascribed to the single effort of a single company, but to the combined effort of all the companies that operate in the area. Therefore, sharing information on reserves, innovations and operational casuistic can generate, as consequence, the operation success.
- Justification: Only applied to services related to the perforation and the geological data. For any scenario;

Table 35: Application of AE.16 in Operative functions per scenario (Chima, 2007; Osinerg, 2005).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5			1 2 3 4 5			1 2 3 4 5

AE.17: Sharing Information into the company to integrate the production operations (Oracle, 2011; Olinto et al., 2018; Swafford et al., 2008)

- Application Analysis: EPPM<sup>9</sup> solutions as a tool to manage information provided by different companies in order to enhance productivity through integrated

<sup>9</sup> Enterprise Project Portfolio Management

development production operations. This tool can enhance the time reduction of reporting and administrative issues, as well as to be accurate when the operation is planned.

Table 36: Application of AE.17 in Operative functions per scenario (Oracle, 2011; Olinto et al., 2018; Swafford, Ghosh and Murthy, 2008).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

AE.18: Cross-channel Coordination (Röthlisberger,2005).

- Application Analysis: Increased revenue through cross-channel coordination, where Drilling Service Contractor can be in coordination with the different contractors as Cementing and the providers of casings, bits and tubing during the execution of the perforation. In addition, this contractor can be in contact with Well Testing Contractor to inform the operation ending and the pumps' supplier when the completion of the wellbore is achieved.

Table 37: Application of AE.18 in Operative functions per scenario (Röthlisberger, 2005).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2 3		1 2 3	1 2 3	1 2 3		1 2	1 2 3	1 2 3

AE.19: Production Optimisation and change the nature of the work (Agility.com, 2017; Bieker et al., 2006; Shuen et al. 2014).

- Application Analysis: Reduce the size of Drilling crews and change the nature of their work.

Table 38: Application of AE.19 in Operative functions per scenario (Agility.com, 2017; Bieker et al., 2006; Shuen et al., 2014).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2					1 2			

AE.20: Early supplier involvement in product technology (Dauda and Yusuf, 2004; Olinto et al., 2018).

- Application Analysis: Early supplier involvement in product technology. For example; changing of Drilling Fluids components to make it less expensive and more environmentally friendly.



- **Justification:** Since the risk of new component usage, this innovation should be applied firstly in high price scenarios. Afterwards, the price decreases when it becomes regularly used.

Table 39: Application of AE.20 in Operative functions per scenario (Dauda and Yusuf, 2004; Olinto et al., 2018).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2 3		1 2 3	1 2 3					

AE.21: Engineer-to-order for tools and equipment (Cibin and Grant, 1996; Dauda and Yusuf, 2004; Shuen et al., 2014).

- **Application Analysis:** Most of the oilfield services industry have an engineer-to-order (ETO) environment. Enterprises must search the core as well as the periphery of their business ecosystem for relevant new technology. The search must scan both rivals and potential collaborators, customers, suppliers, partners, and new entrances that are active in innovative activity.
- **Justification:** ETO requires high investment, it would be applied in high prices scenarios and only in the services where the innovation is highly important.

Table 40: Application of AE.21 in Operative functions per scenario (Cibin and Grant, 1996; Dauda and Yusuf, 2004; Shuen et al., 2014).

Drilling	Stimulation	Cementing	Drilling Fluids	Casing and Tubing	Facilities	Pumps	Bits	Wireline Services
1 2	1 2				1 2			1 2

## 6. Findings and Conclusion

The Figure 21 and 22 show the results in summary for this study.

The figure 21 shows the number of agility enablers per function applied in each scenario, where fourteen of the total agility enablers are applied in all scenarios except in the scenario 3 where it is applied through 13 units. Similarly, many of them would be applied in the Drilling operation with 18 units distributed mostly in scenarios 1 and 2, followed by the cementing service with 14 units distributed mostly in scenarios 4 and 5.

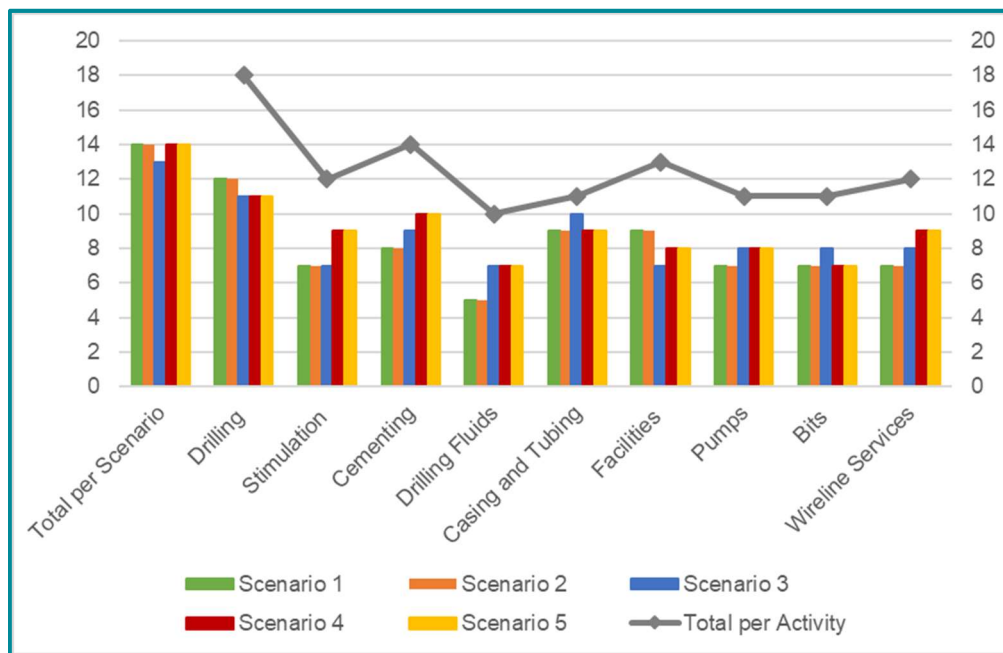


Figure 21: Agility Enablers by operative function in each scenario.

At the same time, the table 21 shows the agility enablers suggested to apply in each scenario of crude oil price. Besides, it lists the number of operational functions in which it will be applied.

From this, it follows that the activities 14, 15 and 17 are applied in all operations, where the Alliance to execute the field's overall development is applied only to scenarios of high crude oil price and positive tendency of operating income such as scenarios 1 and 2.

Otherwise, activity 15 only applies in case of emergency when crude oil price is low and there is a high variability of operating income to ensure a low cost and a rapid response from the contractor. Therefore, it is applied in scenario 3, 4 and 5 (Ernst and Steinhubl, 1997; EY, 2015 and Röthlisberger, 2005).

Furthermore, there are agility enablers applied to the five scenarios, as it is the case of the enablers 7,9,10,13,16 and 17. For example, for enabler 9 related to the quality strategy (TPM and TQM), the low investment in maintenance allows the application of this strategy in any price level (Agarwal et al., 2016; Bieker et al., 2006). Similarly, in the case of the enabler 10 Kanban, as a lean tool that should be applied in any scenario due to the reduction of time and the risk of stand by cost. In fact, this risk could be generated if a material is not available at the time the operation is being executed (Agarwal et al., 2016; Garbie, 2011; Sakhardande, 2011).

Finally, the options to combine the agility enablers application are based on the economic and financial statements of each operating company regarding to the crude oil prices variation. For this case study, the above determined and stated combination is based on 21 agility enablers found and previously applied by other companies of the sector. Moreover, nine operations are highlighted, which are the application approach of the enablers due to the greater economic impact that they would generate. In summary, the five scenarios give a guide about in which situations of price variation and under what business parameters, the company must apply Agility enablers.

For example, there are enablers that could start working from the beginning, no matter the behaviour of the price. However, as long as the price increases, the investment can be focused on encouraging to the contractors to form a vertical integration between each other, to work with 3PL contractors and investing in technology innovation. Indeed, in case there is a decrease after the previous price increase, it should be emphasized in the application of the Agility enablers applied in scenario 4 and 5.

Therefore, many agility enablers application options can be combined considering the business measurement parameters in situations of crude oil price change.

Tabla 41: Detail of Agility enablers applied in each simulation scenario and by Operative Function

	Number of Operative Functions			SCENARIOS					Number of Operative Functions by Agility Enabler
	IT	Agility Enablers	#	1	2	3	4	5	
Vertical Integration	1	Vertical Integration between Contractors	6	✓	✓				
Outsourcing	2	Supplier location close from oilfield	3			✓	✓	✓	
	3	Optimal Pricing Strategy	8				✓	✓	
	4	Long term purchasing agreement	8			✓	✓	✓	
Customise Logistic Network	5	3PL Contractor for Internal transportation and warehousing	5	✓	✓	✓			
	6	Suppling of materials en production line	1	✓	✓	✓			
Internal Operation	7	Re-using or recycling old tools	2	✓	✓	✓	✓	✓	
	8	Decentralisation of Operational decision making	2				✓	✓	
	9	Application of TPM and TQM	5	✓	✓	✓	✓	✓	
	10	Kanban Application	8	✓	✓	✓	✓	✓	
	11	Reduced design cycle time and Lead time	5			✓	✓	✓	
	12	Reduction in Manpower	6				✓	✓	
Alliances	13	Contractual relationships with other operating companies for sharing materials	5	✓	✓	✓	✓	✓	
	14	Execute the field's overall development	9	✓	✓				
	15	Collaborative bidding and rate negotiations with current contractors	9			✓	✓	✓	
Wide Technology for Data Sharing	16	Sharing information on reserves, innovations and operational's cases among companies of the sector	5	✓	✓	✓	✓	✓	
	17	Sharing Information into the company to integrate the production operations	9	✓	✓	✓	✓	✓	
	18	Cross-channel Coordination	7	✓	✓	✓			
Operational Innovation	19	Production Optimisation and change the nature of the work	2	✓	✓				
	20	Early supplier involvement in product technology	3	✓	✓	✓			
	21	Engineer-to-order for tools and equipment	5	✓	✓				

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## 8. Appendix

### Appendix 1: Confirmation email - Research ethics approval is not required.

21/8/2019

Mail - Patsy Margarita Luyo Echevarria (Student) - Outlook

**Confirmation of Receipt of Research Ethics Application: Ms. Patsy Margarita Luyo Echevarría, 17096-NER-May/2019- 19203-1**

donotreply@infonetica.net

Mon 27/05/2019 22:19

To: Patsy Margarita Luyo Echevarria (Student) <1832359@brunel.ac.uk>

Dear Ms. Patsy Margarita Luyo Echevarría

Thank you for your application. On the basis of the information you have provided on the application form, your project should not require research ethics approval.

Please ensure you have considered the following before commencing your research:

- Brunel University Research Integrity Code
- Brunel University Research Data Management Policy
- Brunel University Open Access Policy
- Provisions of the Data Protection Act 1998 and the University Data Protection Policy (further advice is available from the Information Access Officer by emailing [data-protection@brunel.ac.uk](mailto:data-protection@brunel.ac.uk))
- University Health and Safety practice and procedures.

Kind regards,



Professor David Gallear

Chair, University Research Ethics Committee

**Appendix 2: Historical Data for EViews Software to calculate Total Production Cost function .**

Table A1: Appendix 2

Year	PC REAL	q(t) [bbi]	$\omega_1$	$\omega_2$	$\omega_3$	LN(PC)	LN(q)	LN(W1)	LN(W2)	LN(W3)
1999	24,111,054	3,079,477	1	27,411,834	312,978	17.00	14.94	0.00	17.13	12.65
2000	44,711,942	3,501,521	1,865,285	40,589,515	128,001	17.62	15.07	14.44	17.52	11.76
2001	39,536,754	3,410,245	582,805	36,951,265	119,981	17.49	15.04	13.28	17.43	11.70
2002	46,320,470	3,487,378	591,974	37,707,385	1,529,661	17.65	15.06	13.29	17.45	14.24
2003	51,793,422	3,507,870	3,365,372	43,433,392	623,543	17.76	15.07	15.03	17.59	13.34
2004	70,256,229	3,744,314	8,224,193	53,556,274	1,320,704	18.07	15.14	15.92	17.80	14.09
2005	99,993,715	4,080,811	25,839,395	68,222,419	1,170,296	18.42	15.22	17.07	18.04	13.97
2006	132,361,072	4,348,288	27,327,977	80,593,440	3,851,032	18.70	15.29	17.12	18.20	15.16
2007	150,587,571	4,500,133	75,960,168	86,466,418	5,752,053	18.83	15.32	18.15	18.28	15.57
2008	214,304,964	4,676,159	94,097,856	109,165,610	29,407,929	19.18	15.36	18.36	18.51	17.20
2009	125,720,139	4,268,100	46,182,130	74,624,064	8,451,082	18.65	15.27	17.65	18.13	15.95
2010	170,581,501	4,510,303	84,459,370	93,818,128	9,895,361	18.95	15.32	18.25	18.36	16.11
2011	291,593,637	5,315,596	126,926,897	133,202,087	21,388,765	19.49	15.49	18.66	18.71	16.88
2012	305,063,182	5,378,101	134,221,843	140,656,325	15,658,196	19.54	15.50	18.72	18.76	16.57
2013	280,052,820	5,250,978	117,455,151	134,753,599	14,508,221	19.45	15.47	18.58	18.72	16.49
2014	233,716,963	4,750,915	50,089,555	125,692,718	13,471,978	19.27	15.37	17.73	18.65	16.42
2015	132,588,923	3,950,549	568,766	90,687,196	10,257,298	18.70	15.19	13.25	18.32	16.14
2016	109,522,815	3,941,744	1	85,015,900	10,720,113	18.51	15.19	0.00	18.26	16.19
2017	158,623,249	4,085,303	53,612,739	95,075,173	10,953,277	18.88	15.22	17.80	18.37	16.21
2018	206,141,304	4,493,843	76,905,535	115,419,423	13,047,713	19.14	15.32	18.16	18.56	16.38

**Appendix 3: Crude Oil Price fluctuation for simulation scenarios.**

Table A2: Appendix 3 (BBC, 2016, ECB, 2015, EIA, 2019a)

Year	SCENARIO 1			SCENARIO 2			SCENARIO 3			SCENARIO 4			SCENARIO 5		
	COP	WTI	BRENT	COP	WTI	BRENT	COP	WTI	BRENT	COP	WTI	BRENT	COP	WTI	BRENT
2019	71.11	67.88	73.26	70.24	70.15	72.15	70.24	70.15	72.15	67.43	66.45	69.45	71.70	67.88	73.88
2020	71.26	69.72	73.27	77.54	76.13	79.13	94.21	90.12	96.12	55.97	55.13	58.13	72.62	69.72	74.72
2021	72.46	71.23	74.43	82.13	80.23	83.23	93.63	93.25	95.25	53.73	50.14	56.14	71.34	71.23	73.23
2022	72.38	70.52	74.40	94.59	90.12	96.12	70.44	70.34	72.34	53.59	52.78	55.78	70.62	70.52	72.52
2023	74.20	72.10	76.21	99.44	95.13	101.13	98.35	95.13	100.13	50.02	48.32	52.32	82.91	80.04	84.87
2024	77.35	75.21	79.32	100.48	97.24	102.24	66.01	64.12	68.12	48.66	45.13	51.13	69.27	67.34	71.34
2025	79.81	77.92	81.73	103.41	100.13	105.13	52.07	50.35	54.35	41.25	41.51	43.51	64.06	63.12	66.12
2026	82.91	80.04	84.87	98.90	98.45	100.45	72.31	70.34	74.34	34.81	34.23	37.23	64.61	60.88	66.88
2027	85.54	82.34	87.50	106.70	102.45	108.45	66.95	64.12	69.12	31.00	29.54	33.54	57.84	55.12	60.12
2028	87.47	84.05	89.42	104.98	103.53	106.53	51.13	50.35	53.35	29.42	28.90	31.90	56.08	54.31	58.31

### Appendix 4: Calculation of Production Level, Production Level per well, number of drilled, producing and injection wells for simulation scenarios

Table A3: Appendix 4

Year	SCENARIO 2							SCENARIO 3						
	Production Level	Crude Oil Price	Production Level per Well	Producing Wells	Drilled Producing Wells	Injection Wells	Drilled Injection Wells	Production Level	Crude Oil Price	Production Level per Well	Producing Wells	Drilled Producing Wells	Injection Wells	Drilled Injection Wells
Year	Q	COP	PL	D <sub>2</sub>	D <sub>1</sub>	D <sub>32</sub>	D <sub>31</sub>	Q	COP	PL	D <sub>2</sub>	D <sub>1</sub>	D <sub>32</sub>	D <sub>31</sub>
2019	4,426,996.77	70.24	1412	3136	50	85	0	4,426,996.77	70.24	1412	3136	50	85	0
2020	4,581,753.07	77.54	1403	3266	52	86	1	4,935,185.77	94.21	1403	3518	56	86	1
2021	4,678,959.17	82.13	1321	3542	90	92	6	4,922,862.80	93.63	1321	3727	95	92	6
2022	4,943,142.28	94.59	1365	3622	75	89	0	4,431,075.32	70.44	1365	3247	67	89	0
2023	5,046,081.68	99.44	1326	3806	68	92	3	5,022,852.80	98.35	1326	3788	67	92	3
2024	5,068,146.19	100.48	1339	3786	78	92	0	4,337,312.29	66.01	1339	3240	67	92	0
2025	5,130,183.11	103.41	1369	3748	81	91	0	4,041,724.62	52.07	1369	2953	64	91	0
2026	5,034,486.32	98.90	1371	3673	76	93	2	4,470,831.19	72.31	1371	3262	67	93	2
2027	5,199,862.31	106.70	1372	3790	77	94	1	4,357,190.22	66.95	1372	3176	65	94	1
2028	5,163,411.85	104.98	1327	3892	77	98	4	4,021,846.68	51.13	1327	3031	60	98	4

Year	SCENARIO 4							SCENARIO 5						
	Production Level	Crude Oil Price	Production Level per Well	Producing Wells	Drilled Producing Wells	Injection Wells	Drilled Injection Wells	Production Level	Crude Oil Price	Production Level per Well	Producing Wells	Drilled Producing Wells	Injection Wells	Drilled Injection Wells
Year	Q	COP	PL	D <sub>2</sub>	D <sub>1</sub>	D <sub>32</sub>	D <sub>31</sub>	Q	COP	PL	D <sub>2</sub>	D <sub>1</sub>	D <sub>32</sub>	D <sub>31</sub>
2019	4,367,450.28	67.43	1412	3094	50	84	0	4,457,867.13	71.70	1412	3158	51	85	0
2020	4,124,454.46	55.97	1403	2941	47	86	2	4,477,464.23	72.62	1403	3192	51	86	1
2021	4,076,972.62	53.73	1321	3087	79	92	6	4,450,235.22	71.34	1321	3369	86	92	6
2022	4,074,009.21	53.59	1365	2985	62	89	0	4,434,893.62	70.62	1365	3250	67	89	0
2023	3,998,148.51	50.02	1326	3016	54	92	3	4,695,454.61	82.91	1326	3542	63	92	3
2024	3,969,427.65	48.66	1339	2965	61	92	0	4,406,433.01	69.27	1339	3291	68	92	0
2025	3,812,208.76	41.25	1369	2785	61	91	0	4,295,968.29	64.06	1369	3139	68	91	0
2026	3,675,813.76	34.81	1371	2682	55	93	2	4,307,604.69	64.61	1371	3142	65	93	2
2027	3,595,015.87	31.00	1372	2621	53	94	1	4,163,995.67	57.84	1372	3035	62	94	1
2028	3,561,399.66	29.42	1327	2684	53	98	4	4,126,730.22	56.08	1327	3110	62	98	4

**Appendix 5: Development Cost and Lease Equipment Cost for Primary Recovery of Crude Oil Production for simulation scenarios.**

Table A4: Appendix 5 (Ego and Orihuela, 2014; EIA, 2010; EIA, 2019b).

**Development and Equipment for Primary of Crude Oil Production  
(Producing Wells from 4,000 Feet by Rod Lift)**

SECONDARY DATA		SCENARIO 1										
New Producing Wells		10	50	50	86	67	60	70	73	70	70	71
Total Index		100	368.86	369.41	374.01	373.68	380.61	392.62	402.01	413.81	423.87	431.23
BASE			MM									
Component	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	
<b>Development and Producing Equipment:</b>												
Casing and Tubing	113,200	2.1	2.1	3.6	2.8	2.6	3.1	3.3	3.3	3.4	3.5	
Bits	78,800	1.5	1.5	2.5	2.0	1.8	2.2	2.3	2.3	2.3	2.4	
Pumps	98,900	1.8	1.8	3.2	2.5	2.3	2.7	2.9	2.9	2.9	3.0	
<b>Subtotal or Index</b>	<b>290,900</b>	<b>5</b>	<b>5</b>	<b>9</b>	<b>7</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>8</b>	<b>9</b>	<b>9</b>	
<b>Development Services:</b>												
Wireline Services	77,200	1.4	1.4	2.5	1.9	1.8	2.1	2.3	2.2	2.3	2.4	
Drilling Rig	308,510	5.7	5.7	9.9	7.7	7.0	8.5	9.1	8.9	9.2	9.4	
Cementing	227,000	4.2	4.2	7.3	5.7	5.2	6.2	6.7	6.6	6.7	7.0	
Drilling Fluids	196,150	3.6	3.6	6.3	4.9	4.5	5.4	5.8	5.7	5.8	6.0	
Well Testing	68,500	1.3	1.3	2.2	1.7	1.6	1.9	2.0	2.0	2.0	2.1	
Stimulation (Hydraulic Fracturing)	234,200	4.3	4.3	7.5	5.9	5.3	6.4	6.9	6.8	6.9	7.2	
Facilities (Platforms, roads...)	112,800	2.1	2.1	3.6	2.8	2.6	3.1	3.3	3.3	3.3	3.5	
<b>Subtotal or Index</b>	<b>1,224,360</b>	<b>23</b>	<b>23</b>	<b>39</b>	<b>31</b>	<b>28</b>	<b>34</b>	<b>36</b>	<b>35</b>	<b>36</b>	<b>37</b>	
<b>Gathering System:</b>												
Flowlines	48,800	0.9	0.9	1.6	1.2	1.1	1.3	1.4	1.4	1.4	1.5	
Manifold	18,510	0.3	0.3	0.6	0.5	0.4	0.5	0.5	0.5	0.5	0.6	
<b>Subtotal or Index</b>	<b>67,310</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	
<b>Lease Equipment:</b>												
Producing Separator	11,110	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Test Separator	12,910	0.2	0.2	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	
Storage Tanks	36,280	0.7	0.7	1.2	0.9	0.8	1.0	1.1	1.1	1.1	1.1	
Disposal System	27,120	0.5	0.5	0.9	0.7	0.6	0.7	0.8	0.8	0.8	0.8	
LACT Unit	12,620	0.2	0.2	0.4	0.3	0.3	0.3	0.4	0.4	0.4	0.4	
Electrification	67,400	1.2	1.2	2.2	1.7	1.5	1.9	2.0	2.0	2.0	2.1	
<b>Subtotal or Index</b>	<b>167,440</b>	<b>3.1</b>	<b>3.1</b>	<b>5.4</b>	<b>4.2</b>	<b>3.8</b>	<b>4.6</b>	<b>4.9</b>	<b>4.9</b>	<b>5.0</b>	<b>5.1</b>	
<b>TOTAL</b>	<b>1,750,010</b>	<b>32.3</b>	<b>32.3</b>	<b>56.3</b>	<b>43.8</b>	<b>40.0</b>	<b>48.1</b>	<b>51.4</b>	<b>50.7</b>	<b>51.9</b>	<b>53.6</b>	

SECONDARY DATA		SCENARIO 2										SCENARIO 3									
New Producing Wells		50	52	90	75	68	78	81	76	77	77	50	56	95	67	67	67	64	67	65	60
Total Index		365.54	393.37	410.85	458.35	476.85	480.82	491.98	474.77	504.50	497.95	365.54	456.92	454.70	366.28	472.68	349.42	296.27	373.42	352.99	292.70
		MM										MM									
Component		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Development and Producing Equipment:</b>																					
Casing and Tubing		2.1	2.3	4.2	3.9	3.7	4.2	4.5	4.1	4.4	4.3	2.1	2.9	4.9	2.8	3.6	2.7	2.1	2.8	2.6	2.0
Bits		1.4	1.6	2.9	2.7	2.6	3.0	3.1	2.8	3.1	3.0	1.4	2.0	3.4	1.9	2.5	1.8	1.5	2.0	1.8	1.4
Pumps		1.8	2.0	3.7	3.4	3.2	3.7	3.9	3.6	3.8	3.8	1.8	2.5	4.3	2.4	3.1	2.3	1.9	2.5	2.3	1.7
<b>Subtotal or Index</b>		<b>5</b>	<b>6</b>	<b>11</b>	<b>10</b>	<b>9</b>	<b>11</b>	<b>12</b>	<b>10</b>	<b>11</b>	<b>11</b>	<b>5</b>	<b>7</b>	<b>13</b>	<b>7</b>	<b>9</b>	<b>7</b>	<b>6</b>	<b>7</b>	<b>7</b>	<b>5</b>
<b>Development Services:</b>																					
Wireline Services		1.4	1.6	2.9	2.7	2.5	2.9	3.1	2.8	3.0	3.0	1.4	2.0	3.3	1.9	2.4	1.8	1.5	1.9	1.8	1.4
Drilling Rig		5.6	6.3	11.4	10.6	10.0	11.6	12.3	11.1	12.0	11.8	5.6	7.9	13.3	7.6	9.8	7.2	5.8	7.7	7.1	5.4
Cementing		4.1	4.6	8.4	7.8	7.4	8.5	9.0	8.2	8.8	8.7	4.1	5.8	9.8	5.6	7.2	5.3	4.3	5.7	5.2	4.0
Drilling Fluids		3.6	4.0	7.3	6.7	6.4	7.4	7.8	7.1	7.6	7.5	3.6	5.0	8.5	4.8	6.2	4.6	3.7	4.9	4.5	3.4
Well Testing		1.3	1.4	2.5	2.4	2.2	2.6	2.7	2.5	2.7	2.6	1.3	1.8	3.0	1.7	2.2	1.6	1.3	1.7	1.6	1.2
Stimulation (Hydraulic Fracturing)		4.3	4.8	8.7	8.1	7.6	8.8	9.3	8.5	9.1	9.0	4.3	6.0	10.1	5.7	7.4	5.5	4.4	5.9	5.4	4.1
Facilities (Platforms, roads...)		2.1	2.3	4.2	3.9	3.7	4.2	4.5	4.1	4.4	4.3	2.1	2.9	4.9	2.8	3.6	2.6	2.1	2.8	2.6	2.0
<b>Subtotal or Index</b>		<b>22</b>	<b>25</b>	<b>45</b>	<b>42</b>	<b>40</b>	<b>46</b>	<b>49</b>	<b>44</b>	<b>48</b>	<b>47</b>	<b>22</b>	<b>31</b>	<b>53</b>	<b>30</b>	<b>39</b>	<b>29</b>	<b>23</b>	<b>31</b>	<b>28</b>	<b>22</b>
<b>Gathering System:</b>																					
Flowlines		0.9	1.0	1.8	1.7	1.6	1.8	1.9	1.8	1.9	1.9	0.9	1.2	2.1	1.2	1.5	1.1	0.9	1.2	1.1	0.9
Manifold		0.3	0.4	0.7	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.3	0.5	0.8	0.5	0.6	0.4	0.4	0.5	0.4	0.3
<b>Subtotal or Index</b>		<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>3</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>3</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>1</b>
<b>Lease Equipment:</b>																					
Producing Separator		0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2	0.3	0.5	0.3	0.4	0.3	0.2	0.3	0.3	0.2
Test Separator		0.2	0.3	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.2	0.3	0.6	0.3	0.4	0.3	0.2	0.3	0.3	0.2
Storage Tanks		0.7	0.7	1.3	1.2	1.2	1.4	1.4	1.3	1.4	1.4	0.7	0.9	1.6	0.9	1.1	0.8	0.7	0.9	0.8	0.6
Disposal System		0.5	0.6	1.0	0.9	0.9	1.0	1.1	1.0	1.1	1.0	0.5	0.7	1.2	0.7	0.9	0.6	0.5	0.7	0.6	0.5
LACT Unit		0.2	0.3	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.2	0.3	0.5	0.3	0.4	0.3	0.2	0.3	0.3	0.2
Electrification		1.2	1.4	2.5	2.3	2.2	2.5	2.7	2.4	2.6	2.6	1.2	1.7	2.9	1.7	2.1	1.6	1.3	1.7	1.5	1.2
<b>Subtotal or Index</b>		<b>3.1</b>	<b>3.4</b>	<b>6.2</b>	<b>5.8</b>	<b>5.4</b>	<b>6.3</b>	<b>6.7</b>	<b>6.0</b>	<b>6.5</b>	<b>6.4</b>	<b>3.1</b>	<b>4.3</b>	<b>7.2</b>	<b>4.1</b>	<b>5.3</b>	<b>3.9</b>	<b>3.2</b>	<b>4.2</b>	<b>3.8</b>	<b>2.9</b>
<b>TOTAL</b>		<b>32.0</b>	<b>35.8</b>	<b>64.7</b>	<b>60.2</b>	<b>56.7</b>	<b>65.6</b>	<b>69.7</b>	<b>63.1</b>	<b>68.0</b>	<b>67.1</b>	<b>32.0</b>	<b>44.8</b>	<b>75.6</b>	<b>42.9</b>	<b>55.4</b>	<b>41.0</b>	<b>33.2</b>	<b>43.8</b>	<b>40.2</b>	<b>30.7</b>

SECONDARY DATA		SCENARIO 4										SCENARIO 5									
New Producing Wells		50	47	79	62	54	61	61	55	53	53	51	51	86	67	63	68	68	65	62	62
Total Index		354.84	311.15	302.61	302.08	288.44	283.27	255.01	230.48	215.95	209.91	371.09	374.62	369.72	366.96	413.81	361.85	341.98	344.08	318.26	311.56
		MM										MM									
Component		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Development and Producing Equipment:</b>																					
Casing and Tubing		2.0	1.7	2.7	2.1	1.8	2.0	1.8	1.4	1.3	1.3	2.1	2.2	3.6	2.8	3.0	2.8	2.6	2.5	2.2	2.2
Bits		1.4	1.2	1.9	1.5	1.2	1.4	1.2	1.0	0.9	0.9	1.5	1.5	2.5	1.9	2.1	1.9	1.8	1.8	1.6	1.5
Pumps		1.8	1.4	2.4	1.9	1.5	1.7	1.5	1.3	1.1	1.1	1.9	1.9	3.1	2.4	2.6	2.4	2.3	2.2	2.0	1.9
<b>Subtotal or Index</b>		<b>5</b>	<b>4</b>	<b>7</b>	<b>5</b>	<b>5</b>	<b>5</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>3</b>	<b>6</b>	<b>6</b>	<b>9</b>	<b>7</b>	<b>8</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>6</b>	<b>6</b>
<b>Development Services:</b>																					
Wireline Services		1.4	1.1	1.8	1.4	1.2	1.3	1.2	1.0	0.9	0.9	1.5	1.5	2.5	1.9	2.0	1.9	1.8	1.7	1.5	1.5
Drilling Rig		5.5	4.5	7.4	5.8	4.8	5.3	4.8	3.9	3.5	3.4	5.8	5.9	9.8	7.6	8.0	7.6	7.2	6.9	6.1	6.0
Cementing		4.0	3.3	5.4	4.3	3.5	3.9	3.5	2.9	2.6	2.5	4.3	4.3	7.2	5.6	5.9	5.6	5.3	5.1	4.5	4.4
Drilling Fluids		3.5	2.9	4.7	3.7	3.1	3.4	3.1	2.5	2.2	2.2	3.7	3.7	6.2	4.8	5.1	4.8	4.6	4.4	3.9	3.8
Well Testing		1.2	1.0	1.6	1.3	1.1	1.2	1.1	0.9	0.8	0.8	1.3	1.3	2.2	1.7	1.8	1.7	1.6	1.5	1.4	1.3
Stimulation (Hydraulic Fracturing)		4.2	3.4	5.6	4.4	3.6	4.0	3.6	3.0	2.7	2.6	4.4	4.5	7.4	5.8	6.1	5.8	5.4	5.2	4.6	4.5
Facilities (Platforms, roads...)		2.0	1.6	2.7	2.1	1.8	1.9	1.8	1.4	1.3	1.3	2.1	2.2	3.6	2.8	2.9	2.8	2.6	2.5	2.2	2.2
<b>Subtotal or Index</b>		<b>22</b>	<b>18</b>	<b>29</b>	<b>23</b>	<b>19</b>	<b>21</b>	<b>19</b>	<b>16</b>	<b>14</b>	<b>14</b>	<b>23</b>	<b>23</b>	<b>39</b>	<b>30</b>	<b>32</b>	<b>30</b>	<b>28</b>	<b>27</b>	<b>24</b>	<b>24</b>
<b>Gathering System:</b>																					
Flowlines		0.9	0.7	1.2	0.9	0.8	0.8	0.8	0.6	0.6	0.5	0.9	0.9	1.6	1.2	1.3	1.2	1.1	1.1	1.0	0.9
Manifold		0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.4	0.4	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
<b>Subtotal or Index</b>		<b>1</b>	<b>1</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>1</b>
<b>Lease Equipment:</b>																					
Producing Separator		0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Test Separator		0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2
Storage Tanks		0.6	0.5	0.9	0.7	0.6	0.6	0.6	0.5	0.4	0.4	0.7	0.7	1.2	0.9	0.9	0.9	0.8	0.8	0.7	0.7
Disposal System		0.5	0.4	0.6	0.5	0.4	0.5	0.4	0.3	0.3	0.3	0.5	0.5	0.9	0.7	0.7	0.7	0.6	0.6	0.5	0.5
LACT Unit		0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2
Electrification		1.2	1.0	1.6	1.3	1.0	1.2	1.0	0.9	0.8	0.7	1.3	1.3	2.1	1.7	1.8	1.7	1.6	1.5	1.3	1.3
<b>Subtotal or Index</b>		<b>3.0</b>	<b>2.4</b>	<b>4.0</b>	<b>3.1</b>	<b>2.6</b>	<b>2.9</b>	<b>2.6</b>	<b>2.1</b>	<b>1.9</b>	<b>1.9</b>	<b>3.2</b>	<b>3.2</b>	<b>5.3</b>	<b>4.1</b>	<b>4.4</b>	<b>4.1</b>	<b>3.9</b>	<b>3.7</b>	<b>3.3</b>	<b>3.2</b>
<b>TOTAL</b>		<b>31.0</b>	<b>25.6</b>	<b>41.8</b>	<b>32.8</b>	<b>27.3</b>	<b>30.2</b>	<b>27.2</b>	<b>22.2</b>	<b>20.0</b>	<b>19.5</b>	<b>33.1</b>	<b>33.4</b>	<b>55.6</b>	<b>43.0</b>	<b>45.6</b>	<b>43.1</b>	<b>40.7</b>	<b>39.1</b>	<b>34.5</b>	<b>33.8</b>

**Appendix 6: Annual Operating Costs for Primary Recovery Crude Oil Production for simulation scenarios.**

Table A5: Appendix 6 (Ego and Orihuela, 2014; EIA, 2010; EIA, 2019b).

**Annual Operating Costs for Primary Crude Oil Production  
(Producing Wells from 4,000 Feet by Rod Lift)**

SECONDARY DATA		SCENARIO 1									
Producing Wells		3149	3172	3387	3277	3402	3419	3382	3425	3464	3612
INDEX	100	368.86	369.41	374.01	373.68	380.61	392.62	402.01	413.81	423.87	431.23
Component	BASE 1994	MM									
		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Normal Daily Expense:</b>											
Supervision and Overhead..	21,900	10.2	10.3	11.1	10.7	11.3	11.8	11.9	12.4	12.9	13.6
Labor (pumper).....	26,500	12.3	12.4	13.4	13.0	13.7	14.2	14.4	15.0	15.6	16.5
Auto Usage.....	6,800	3.2	3.2	3.4	3.3	3.5	3.7	3.7	3.9	4.0	4.2
Chemicals.....	3,700	1.7	1.7	1.9	1.8	1.9	2.0	2.0	2.1	2.2	2.3
Fuel, Power & Water.....	74,700	34.7	35.0	37.9	36.6	38.7	40.1	40.6	42.3	43.9	46.5
Operative Supplies.....	1,800	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1
<b>Subtotal or Index.....</b>	<b>135,400</b>	<b>62.9</b>	<b>63.5</b>	<b>68.6</b>	<b>66.3</b>	<b>70.1</b>	<b>72.7</b>	<b>73.6</b>	<b>76.8</b>	<b>79.5</b>	<b>84.4</b>
<b>Surface Maintenance, Repair &amp; Services:</b>											
Labor (roustabout).....	10,800	5.0	5.1	5.5	5.3	5.6	5.8	5.9	6.1	6.3	6.7
Supplies & Services.....	7,000	3.3	3.3	3.5	3.4	3.6	3.8	3.8	4.0	4.1	4.4
Equipment Usage.....	3,300	1.5	1.5	1.7	1.6	1.7	1.8	1.8	1.9	1.9	2.1
<b>Subtotal or Index.....</b>	<b>21,100</b>	<b>9.8</b>	<b>9.9</b>	<b>10.7</b>	<b>10.3</b>	<b>10.9</b>	<b>11.3</b>	<b>11.5</b>	<b>12.0</b>	<b>12.4</b>	<b>13.1</b>
<b>Subsurface Maintenance, Repair &amp; Services:</b>											
Workover Rig Services	17,100	7.9	8.0	8.7	8.4	8.9	9.2	9.3	9.7	10.0	10.7
Remedial Services	2,500	1.2	1.2	1.3	1.2	1.3	1.3	1.4	1.4	1.5	1.6
Equipment Repair	11,300	5.3	5.3	5.7	5.5	5.9	6.1	6.1	6.4	6.6	7.0
Other	500	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3
<b>Subtotal or Index.....</b>	<b>31,400</b>	<b>14.6</b>	<b>14.7</b>	<b>15.9</b>	<b>15.4</b>	<b>16.3</b>	<b>16.9</b>	<b>17.1</b>	<b>17.8</b>	<b>18.4</b>	<b>19.6</b>
<b>TOTAL</b>	<b>187,900.0</b>	<b>87.3</b>	<b>88.1</b>	<b>95.2</b>	<b>92.0</b>	<b>97.3</b>	<b>100.9</b>	<b>102.2</b>	<b>106.5</b>	<b>110.4</b>	<b>117.1</b>



SECONDARY DATA		SCENARIO 2										SCENARIO 3									
Producing Wells		3136	3266	3542	3622	3806	3786	3748	3673	3790	3892	3136	3518	3727	3247	3788	3240	2953	3262	3176	3031
INDEX	100	365.54	393.37	410.85	458.35	476.85	480.82	491.98	474.77	504.50	497.95	365.54	456.92	454.70	366.28	472.68	349.42	296.27	373.42	352.99	292.70
BASE		MM										MM									
Component	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Normal Daily Expense:</b>																					
Supervision and Overhead..	21,900	10.0	11.3	12.7	14.5	15.9	15.9	16.2	15.3	16.7	17.0	10.0	14.1	14.8	10.4	15.7	9.9	7.7	10.7	9.8	7.8
Labor (pumper).....	26,500	12.2	13.6	15.4	17.6	19.2	19.3	19.5	18.5	20.3	20.5	12.2	17.0	18.0	12.6	19.0	12.0	9.3	12.9	11.9	9.4
Auto Usage.....	6,800	3.1	3.5	4.0	4.5	4.9	5.0	5.0	4.7	5.2	5.3	3.1	4.4	4.6	3.2	4.9	3.1	2.4	3.3	3.0	2.4
Chemicals.....	3,700	1.7	1.9	2.2	2.5	2.7	2.7	2.7	2.6	2.8	2.9	1.7	2.4	2.5	1.8	2.6	1.7	1.3	1.8	1.7	1.3
Fuel, Power & Water.....	74,700	34.3	38.4	43.5	49.6	54.2	54.4	55.1	52.1	57.1	57.9	34.3	48.0	50.6	35.5	53.5	33.8	26.1	36.4	33.5	26.5
Operative Supplies.....	1,800	0.8	0.9	1.0	1.2	1.3	1.3	1.3	1.3	1.4	1.4	0.8	1.2	1.2	0.9	1.3	0.8	0.6	0.9	0.8	0.6
<b>Subtotal or Index.....</b>	<b>135,400</b>	<b>62.1</b>	<b>69.6</b>	<b>78.8</b>	<b>89.9</b>	<b>98.3</b>	<b>98.6</b>	<b>99.9</b>	<b>94.4</b>	<b>103.6</b>	<b>105.0</b>	<b>62.1</b>	<b>87.1</b>	<b>91.8</b>	<b>64.4</b>	<b>97.0</b>	<b>61.3</b>	<b>47.4</b>	<b>66.0</b>	<b>60.7</b>	<b>48.0</b>
<b>Surface Maintenance, Repair &amp; Services:</b>																					
Labor (roustabout).....	10,800	5.0	5.6	6.3	7.2	7.8	7.9	8.0	7.5	8.3	8.4	5.0	6.9	7.3	5.1	7.7	4.9	3.8	5.3	4.8	3.8
Supplies & Services.....	7,000	3.2	3.6	4.1	4.6	5.1	5.1	5.2	4.9	5.4	5.4	3.2	4.5	4.7	3.3	5.0	3.2	2.4	3.4	3.1	2.5
Equipment Usage.....	3,300	1.5	1.7	1.9	2.2	2.4	2.4	2.4	2.3	2.5	2.6	1.5	2.1	2.2	1.6	2.4	1.5	1.2	1.6	1.5	1.2
<b>Subtotal or Index.....</b>	<b>21,100</b>	<b>9.7</b>	<b>10.8</b>	<b>12.3</b>	<b>14.0</b>	<b>15.3</b>	<b>15.4</b>	<b>15.6</b>	<b>14.7</b>	<b>16.1</b>	<b>16.4</b>	<b>9.7</b>	<b>13.6</b>	<b>14.3</b>	<b>10.0</b>	<b>15.1</b>	<b>9.6</b>	<b>7.4</b>	<b>10.3</b>	<b>9.5</b>	<b>7.5</b>
<b>Subsurface Maintenance, Repair &amp; Services:</b>																					
Workover Rig Services	17,100	7.8	8.8	10.0	11.4	12.4	12.5	12.6	11.9	13.1	13.3	7.8	11.0	11.6	8.1	12.2	7.7	6.0	8.3	7.7	6.1
Remedial Services	2,500	1.1	1.3	1.5	1.7	1.8	1.8	1.8	1.7	1.9	1.9	1.1	1.6	1.7	1.2	1.8	1.1	0.9	1.2	1.1	0.9
Equipment Repair	11,300	5.2	5.8	6.6	7.5	8.2	8.2	8.3	7.9	8.6	8.8	5.2	7.3	7.7	5.4	8.1	5.1	4.0	5.5	5.1	4.0
Other	500	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.4	0.4	0.2	0.3	0.3	0.2	0.4	0.2	0.2	0.2	0.2	0.2
<b>Subtotal or Index.....</b>	<b>31,400</b>	<b>14.4</b>	<b>16.1</b>	<b>18.3</b>	<b>20.9</b>	<b>22.8</b>	<b>22.9</b>	<b>23.2</b>	<b>21.9</b>	<b>24.0</b>	<b>24.3</b>	<b>14.4</b>	<b>20.2</b>	<b>21.3</b>	<b>14.9</b>	<b>22.5</b>	<b>14.2</b>	<b>11.0</b>	<b>15.3</b>	<b>14.1</b>	<b>11.1</b>
<b>TOTAL</b>	<b>187,900.0</b>	<b>86.2</b>	<b>96.6</b>	<b>109.4</b>	<b>124.8</b>	<b>136.4</b>	<b>136.8</b>	<b>138.6</b>	<b>131.1</b>	<b>143.7</b>	<b>145.7</b>	<b>86.2</b>	<b>120.8</b>	<b>127.4</b>	<b>89.4</b>	<b>134.6</b>	<b>85.1</b>	<b>65.8</b>	<b>91.6</b>	<b>84.3</b>	<b>66.7</b>

SECONDARY DATA		SCENARIO 4										SCENARIO 5										
Producing Wells		3094	2941	3087	2985	3016	2965	2785	2682	2621	2684	3158	3192	3369	3250	3542	3291	3139	3142	3035	3110	
INDEX		100	354.84	311.15	302.61	302.08	288.44	283.27	255.01	230.48	215.95	209.91	371.09	374.62	369.72	366.96	413.81	361.85	341.98	344.08	318.26	311.56
Component	BASE	MM										MM										
	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	
<b>Normal Daily Expense:</b>																						
Supervision and Overhead..	21,900	9.6	8.0	8.2	7.9	7.6	7.4	6.2	5.4	5.0	4.9	10.3	10.5	10.9	10.4	12.8	10.4	9.4	9.5	8.5	8.5	
Labor (pumper).....	26,500	11.6	9.7	9.9	9.6	9.2	8.9	7.5	6.6	6.0	6.0	12.4	12.7	13.2	12.6	15.5	12.6	11.4	11.5	10.2	10.3	
Auto Usage.....	6,800	3.0	2.5	2.5	2.5	2.4	2.3	1.9	1.7	1.5	1.5	3.2	3.3	3.4	3.2	4.0	3.2	2.9	2.9	2.6	2.6	
Chemicals.....	3,700	1.6	1.4	1.4	1.3	1.3	1.2	1.1	0.9	0.8	0.8	1.7	1.8	1.8	1.8	2.2	1.8	1.6	1.6	1.4	1.4	
Fuel, Power & Water.....	74,700	32.8	27.3	27.9	26.9	26.0	25.1	21.2	18.5	16.9	16.8	35.0	35.7	37.2	35.6	43.8	35.6	32.1	32.3	28.9	29.0	
Operative Supplies.....	1,800	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.4	0.4	0.4	0.8	0.9	0.9	0.9	1.1	0.9	0.8	0.8	0.7	0.7	
<b>Subtotal or Index.....</b>	<b>135,400</b>	<b>59.5</b>	<b>49.6</b>	<b>50.6</b>	<b>48.8</b>	<b>47.1</b>	<b>45.5</b>	<b>38.5</b>	<b>33.5</b>	<b>30.7</b>	<b>30.5</b>	<b>63.5</b>	<b>64.8</b>	<b>67.5</b>	<b>64.6</b>	<b>79.4</b>	<b>64.5</b>	<b>58.1</b>	<b>58.6</b>	<b>52.3</b>	<b>52.5</b>	
<b>Surface Maintenance, Repair &amp; Services:</b>																						
Labor (roustabout).....	10,800	4.7	4.0	4.0	3.9	3.8	3.6	3.1	2.7	2.4	2.4	5.1	5.2	5.4	5.2	6.3	5.1	4.6	4.7	4.2	4.2	
Supplies & Services.....	7,000	3.1	2.6	2.6	2.5	2.4	2.4	2.0	1.7	1.6	1.6	3.3	3.3	3.5	3.3	4.1	3.3	3.0	3.0	2.7	2.7	
Equipment Usage.....	3,300	1.4	1.2	1.2	1.2	1.1	1.1	0.9	0.8	0.7	0.7	1.5	1.6	1.6	1.6	1.9	1.6	1.4	1.4	1.3	1.3	
<b>Subtotal or Index.....</b>	<b>21,100</b>	<b>9.3</b>	<b>7.7</b>	<b>7.9</b>	<b>7.6</b>	<b>7.3</b>	<b>7.1</b>	<b>6.0</b>	<b>5.2</b>	<b>4.8</b>	<b>4.8</b>	<b>9.9</b>	<b>10.1</b>	<b>10.5</b>	<b>10.1</b>	<b>12.4</b>	<b>10.1</b>	<b>9.1</b>	<b>9.1</b>	<b>8.2</b>	<b>8.2</b>	
<b>Subsurface Maintenance, Repair &amp; Services:</b>																						
Workover Rig Services	17,100	7.5	6.3	6.4	6.2	6.0	5.7	4.9	4.2	3.9	3.9	8.0	8.2	8.5	8.2	10.0	8.1	7.3	7.4	6.6	6.6	
Remedial Services	2,500	1.1	0.9	0.9	0.9	0.9	0.8	0.7	0.6	0.6	0.6	1.2	1.2	1.2	1.2	1.5	1.2	1.1	1.1	1.0	1.0	
Equipment Repair	11,300	5.0	4.1	4.2	4.1	3.9	3.8	3.2	2.8	2.6	2.5	5.3	5.4	5.6	5.4	6.6	5.4	4.9	4.9	4.4	4.4	
Other	500	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	
<b>Subtotal or Index.....</b>	<b>31,400</b>	<b>13.8</b>	<b>11.5</b>	<b>11.7</b>	<b>11.3</b>	<b>10.9</b>	<b>10.5</b>	<b>8.9</b>	<b>7.8</b>	<b>7.1</b>	<b>7.1</b>	<b>14.7</b>	<b>15.0</b>	<b>15.6</b>	<b>15.0</b>	<b>18.4</b>	<b>15.0</b>	<b>13.5</b>	<b>13.6</b>	<b>12.1</b>	<b>12.2</b>	
<b>TOTAL</b>	<b>187,900.0</b>	<b>82.5</b>	<b>68.8</b>	<b>70.2</b>	<b>67.8</b>	<b>65.4</b>	<b>63.1</b>	<b>53.4</b>	<b>46.5</b>	<b>42.5</b>	<b>42.3</b>	<b>88.1</b>	<b>89.9</b>	<b>93.6</b>	<b>89.6</b>	<b>110.2</b>	<b>89.5</b>	<b>80.7</b>	<b>81.3</b>	<b>72.6</b>	<b>72.8</b>	

**Appendix 7: Additional Lease Equipment and Operation for Secondary Recovery Crude Oil Production per simulation scenario.**

Table A6: Appendix 7 (Ego and Orihuela, 2014; EIA, 2010; EIA, 2019b).

SECONDARY DATA		SCENARIO 1									
Drilled Injection Wells 11		0	1	6	0	3	0	0	2	1	4
INDEX 100		368.86	369.41	374.01	373.68	380.61	392.62	402.01	413.81	423.87	431.23
BASE		MM									
Component	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Injection Equipment:</b>											
Supply Wells.....	127900	0.00	0.04	0.26	0.00	0.13	0.00	0.00	0.10	0.05	0.20
Plant.....	96300	0.00	0.03	0.20	0.00	0.10	0.00	0.00	0.07	0.04	0.15
Distribution Lines.....	76200	0.00	0.03	0.16	0.00	0.08	0.00	0.00	0.06	0.03	0.12
Header.....	48700	0.00	0.02	0.10	0.00	0.05	0.00	0.00	0.04	0.02	0.08
Electrical Service.....	87600	0.00	0.03	0.18	0.00	0.09	0.00	0.00	0.07	0.03	0.14
<b>Subtotal or Index..</b>	<b>436,700</b>	<b>-</b>	<b>0</b>	<b>1</b>	<b>-</b>	<b>0</b>	<b>-</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>1</b>
<b>Producing Equipment:</b>											
Tubing Replacement.....	88700	0.00	0.03	0.18	0.00	0.09	0.00	0.00	0.07	0.03	0.14
Rods & Pumps.....	59000	0.00	0.02	0.12	0.00	0.06	0.00	0.00	0.04	0.02	0.09
Pumping Equipment.....	284100	0.00	0.10	0.58	0.00	0.29	0.00	0.00	0.21	0.11	0.45
<b>Subtotal or Index..</b>	<b>431,800</b>	<b>-</b>	<b>0.15</b>	<b>0.88</b>	<b>0.00</b>	<b>0.45</b>	<b>0.00</b>	<b>0.00</b>	<b>0.32</b>	<b>0.17</b>	<b>0.68</b>
<b>Injection Wells</b>	<b>11</b>	<b>85</b>	<b>86</b>	<b>92</b>	<b>89</b>	<b>92</b>	<b>92</b>	<b>91</b>	<b>93</b>	<b>94</b>	<b>98</b>
<b>Normal Daily Expense:</b>											
Supervision and Overhead..	47700	1.36	1.38	1.49	1.44	1.52	1.57	1.59	1.67	1.73	1.83
Labor (pumper).....	51800	1.48	1.50	1.62	1.57	1.65	1.70	1.72	1.81	1.88	1.99
Chemicals.....	6700	0.19	0.19	0.21	0.20	0.21	0.22	0.22	0.23	0.24	0.26
Fuel, Power & Water.....	120000	3.42	3.47	3.75	3.63	3.82	3.94	3.99	4.20	4.35	4.61
Operative Supplies.....	6400	0.18	0.18	0.20	0.19	0.20	0.21	0.21	0.22	0.23	0.25
<b>Subtotal or Index.....</b>	<b>232,600</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>9</b>
<b>Surface Maintenance, Repair &amp; Services:</b>											
Labor (roustabout).....	26700	0.76	0.77	0.84	0.81	0.85	0.88	0.89	0.93	0.97	1.03
Supplies & Services.....	37600	1.07	1.09	1.18	1.14	1.20	1.23	1.25	1.32	1.36	1.44
Equipment Usage.....	14400	0.41	0.42	0.45	0.44	0.46	0.47	0.48	0.50	0.52	0.55
Other.....	4400	0.13	0.13	0.14	0.13	0.14	0.14	0.15	0.15	0.16	0.17
<b>Subtotal or Index.....</b>	<b>83,100</b>	<b>2.37</b>	<b>2.40</b>	<b>2.60</b>	<b>2.51</b>	<b>2.65</b>	<b>2.73</b>	<b>2.76</b>	<b>2.91</b>	<b>3.01</b>	<b>3.19</b>
<b>Subsurface Maintenance, Repair &amp; Services:</b>											
Workover Rig Services.....	46400	1.32	1.34	1.45	1.40	1.48	1.52	1.54	1.62	1.68	1.78
Remedial Services.....	13900	0.40	0.40	0.43	0.42	0.44	0.46	0.46	0.49	0.50	0.53
Equipment Repair.....	11200	0.32	0.32	0.35	0.34	0.36	0.37	0.37	0.39	0.41	0.43
Other.....	9100	0.26	0.26	0.28	0.28	0.29	0.30	0.30	0.32	0.33	0.35
<b>Subtotal or Index.....</b>	<b>80,600</b>	<b>2.30</b>	<b>2.33</b>	<b>2.52</b>	<b>2.44</b>	<b>2.57</b>	<b>2.65</b>	<b>2.68</b>	<b>2.82</b>	<b>2.92</b>	<b>3.10</b>
<b>TOTAL</b>	<b>1,264,800</b>	<b>11</b>	<b>12</b>	<b>14</b>	<b>12</b>	<b>14</b>	<b>13</b>	<b>13</b>	<b>15</b>	<b>15</b>	<b>17</b>

SECONDARY DATA		SCENARIO 2										SCENARIO 3									
Drilled Injection Wells	11	0	1	6	0	3	0	0	2	1	4	0	1	6	0	3	0	0	2	1	4
INDEX	100	365.54	393.37	410.85	458.35	476.85	480.82	491.98	474.77	504.50	497.95	365.54	456.92	454.70	366.28	472.68	349.42	296.27	373.42	352.99	292.70
BASE		MM										MM									
Component	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Injection Equipment:</b>																					
Supply Wells.....	127900	0.00	0.05	0.29	0.00	0.17	0.00	0.00	0.11	0.06	0.23	0.00	0.05	0.32	0.00	0.16	0.00	0.00	0.09	0.04	0.14
Plant.....	96300	0.00	0.03	0.22	0.00	0.13	0.00	0.00	0.08	0.04	0.17	0.00	0.04	0.24	0.00	0.12	0.00	0.00	0.07	0.03	0.10
Distribution Lines....	76200	0.00	0.03	0.17	0.00	0.10	0.00	0.00	0.07	0.03	0.14	0.00	0.03	0.19	0.00	0.10	0.00	0.00	0.05	0.02	0.08
Header.....	48700	0.00	0.02	0.11	0.00	0.06	0.00	0.00	0.04	0.02	0.09	0.00	0.02	0.12	0.00	0.06	0.00	0.00	0.03	0.02	0.05
Electrical Service....	87600	0.00	0.03	0.20	0.00	0.11	0.00	0.00	0.08	0.04	0.16	0.00	0.04	0.22	0.00	0.11	0.00	0.00	0.06	0.03	0.09
<b>Subtotal or Index..</b>	<b>436,700</b>	<b>-</b>	<b>0</b>	<b>1</b>	<b>-</b>	<b>1</b>	<b>-</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>-</b>	<b>0</b>	<b>1</b>	<b>-</b>	<b>1</b>	<b>-</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Producing Equipment:</b>																					
Tubing Replacement.....	88700	0.00	0.03	0.20	0.00	0.12	0.00	0.00	0.08	0.04	0.16	0.00	0.04	0.22	0.00	0.11	0.00	0.00	0.06	0.03	0.09
Rods & Pumps.....	59000	0.00	0.02	0.13	0.00	0.08	0.00	0.00	0.05	0.03	0.11	0.00	0.02	0.15	0.00	0.08	0.00	0.00	0.04	0.02	0.06
Pumping Equipment.....	284100	0.00	0.10	0.64	0.00	0.37	0.00	0.00	0.25	0.13	0.51	0.00	0.12	0.70	0.00	0.37	0.00	0.00	0.19	0.09	0.30
<b>Subtotal or Index..</b>	<b>431,800</b>	<b>-</b>	<b>0.15</b>	<b>0.97</b>	<b>0.00</b>	<b>0.56</b>	<b>0.00</b>	<b>0.00</b>	<b>0.37</b>	<b>0.20</b>	<b>0.78</b>	<b>-</b>	<b>0.18</b>	<b>1.07</b>	<b>0.00</b>	<b>0.56</b>	<b>0.00</b>	<b>0.00</b>	<b>0.29</b>	<b>0.14</b>	<b>0.46</b>
<b>Injection Wells</b>	<b>11</b>	<b>85</b>	<b>86</b>	<b>92</b>	<b>89</b>	<b>92</b>	<b>92</b>	<b>91</b>	<b>93</b>	<b>94</b>	<b>98</b>	<b>85</b>	<b>86</b>	<b>92</b>	<b>89</b>	<b>92</b>	<b>92</b>	<b>91</b>	<b>93</b>	<b>94</b>	<b>98</b>
<b>Normal Daily Expense:</b>																					
Supervision and Overhead..	47700	1.35	1.47	1.64	1.77	1.90	1.92	1.94	1.91	2.06	2.12	1.35	1.70	1.81	1.41	1.89	1.39	1.17	1.51	1.44	1.24
Labor (pumper).....	51800	1.46	1.59	1.78	1.92	2.07	2.08	2.11	2.08	2.23	2.30	1.46	1.85	1.97	1.54	2.05	1.51	1.27	1.64	1.56	1.35
Chemicals.....	6700	0.19	0.21	0.23	0.25	0.27	0.27	0.27	0.27	0.29	0.30	0.19	0.24	0.25	0.20	0.26	0.20	0.16	0.21	0.20	0.17
Fuel, Power & Water.....	120000	3.39	3.69	4.12	4.45	4.79	4.83	4.88	4.82	5.17	5.32	3.39	4.29	4.56	3.56	4.74	3.51	2.94	3.79	3.62	3.13
Operative Supplies.....	6400	0.18	0.20	0.22	0.24	0.26	0.26	0.26	0.26	0.28	0.28	0.18	0.23	0.24	0.19	0.25	0.19	0.16	0.20	0.19	0.17
<b>Subtotal or Index....</b>	<b>232,600</b>	<b>7</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>9</b>	<b>9</b>	<b>9</b>	<b>9</b>	<b>10</b>	<b>10</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>7</b>	<b>9</b>	<b>7</b>	<b>6</b>	<b>7</b>	<b>7</b>	<b>6</b>
<b>Surface Maintenance, Repair &amp; Services:</b>																					
Labor (roustabout).....	26700	0.75	0.82	0.92	0.99	1.06	1.07	1.09	1.07	1.15	1.18	0.75	0.95	1.02	0.79	1.06	0.78	0.65	0.84	0.81	0.70
Supplies & Services.....	37600	1.06	1.16	1.29	1.39	1.50	1.51	1.53	1.51	1.62	1.67	1.06	1.34	1.43	1.11	1.49	1.10	0.92	1.19	1.13	0.98
Equipment Usage.....	14400	0.41	0.44	0.49	0.53	0.57	0.58	0.59	0.58	0.62	0.64	0.41	0.51	0.55	0.43	0.57	0.42	0.35	0.45	0.43	0.38
Other.....	4400	0.12	0.14	0.15	0.16	0.18	0.18	0.18	0.18	0.19	0.20	0.12	0.16	0.17	0.13	0.17	0.13	0.11	0.14	0.13	0.11
<b>Subtotal or Index....</b>	<b>83,100</b>	<b>2.35</b>	<b>2.56</b>	<b>2.86</b>	<b>3.08</b>	<b>3.31</b>	<b>3.34</b>	<b>3.38</b>	<b>3.34</b>	<b>3.58</b>	<b>3.69</b>	<b>2.35</b>	<b>2.97</b>	<b>3.16</b>	<b>2.46</b>	<b>3.29</b>	<b>2.43</b>	<b>2.04</b>	<b>2.62</b>	<b>2.51</b>	<b>2.17</b>
<b>Subsurface Maintenance, Repair &amp; Services:</b>																					
Workover Rig Services.....	46400	1.31	1.43	1.59	1.72	1.85	1.87	1.89	1.86	2.00	2.06	1.31	1.66	1.76	1.38	1.83	1.36	1.14	1.46	1.40	1.21
Remedial Services.....	13900	0.39	0.43	0.48	0.52	0.55	0.56	0.57	0.56	0.60	0.62	0.39	0.50	0.53	0.41	0.55	0.41	0.34	0.44	0.42	0.36
Equipment Repair.....	11200	0.32	0.34	0.38	0.42	0.45	0.45	0.46	0.45	0.48	0.50	0.32	0.40	0.43	0.33	0.44	0.33	0.27	0.35	0.34	0.29
Other.....	9100	0.26	0.28	0.31	0.34	0.36	0.37	0.37	0.37	0.39	0.40	0.26	0.33	0.35	0.27	0.36	0.27	0.22	0.29	0.27	0.24
<b>Subtotal or Index....</b>	<b>80,600</b>	<b>2.28</b>	<b>2.48</b>	<b>2.77</b>	<b>2.99</b>	<b>3.21</b>	<b>3.24</b>	<b>3.28</b>	<b>3.24</b>	<b>3.47</b>	<b>3.58</b>	<b>2.28</b>	<b>2.88</b>	<b>3.07</b>	<b>2.39</b>	<b>3.19</b>	<b>2.36</b>	<b>1.98</b>	<b>2.54</b>	<b>2.43</b>	<b>2.10</b>
<b>TOTAL</b>	<b>1,264,800</b>	<b>11</b>	<b>12</b>	<b>16</b>	<b>15</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>17</b>	<b>17</b>	<b>19</b>	<b>11</b>	<b>15</b>	<b>17</b>	<b>12</b>	<b>17</b>	<b>12</b>	<b>10</b>	<b>13</b>	<b>12</b>	<b>11</b>

SECONDARY DATA		SCENARIO 4										SCENARIO 5									
Drilled Injection Wells	11	0	2	6	0	3	0	0	2	1	4	0	1	6	0	3	0	0	2	1	4
INDEX	100	354.84	311.15	302.61	302.08	288.44	283.27	255.01	230.48	215.95	209.91	371.09	374.62	369.72	366.96	413.81	361.85	341.98	344.08	318.26	311.56
BASE		MM										MM									
Component	1994	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
<b>Injection Equipment:</b>																					
Supply Wells.....	127900	0.00	0.07	0.21	0.00	0.10	0.00	0.00	0.05	0.03	0.10	0.00	0.04	0.26	0.00	0.14	0.00	0.00	0.08	0.04	0.14
Plant.....	96300	0.00	0.05	0.16	0.00	0.08	0.00	0.00	0.04	0.02	0.07	0.00	0.03	0.19	0.00	0.11	0.00	0.00	0.06	0.03	0.11
Distribution Lines....	76200	0.00	0.04	0.13	0.00	0.06	0.00	0.00	0.03	0.01	0.06	0.00	0.03	0.15	0.00	0.09	0.00	0.00	0.05	0.02	0.09
Header.....	48700	0.00	0.03	0.08	0.00	0.04	0.00	0.00	0.02	0.01	0.04	0.00	0.02	0.10	0.00	0.05	0.00	0.00	0.03	0.01	0.06
Electrical Service....	87600	0.00	0.05	0.14	0.00	0.07	0.00	0.00	0.04	0.02	0.07	0.00	0.03	0.18	0.00	0.10	0.00	0.00	0.05	0.03	0.10
<b>Subtotal or Index..</b>	<b>436,700</b>	<b>-</b>	<b>0</b>	<b>1</b>	<b>-</b>	<b>0</b>	<b>-</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>-</b>	<b>0</b>	<b>1</b>	<b>-</b>	<b>0</b>	<b>-</b>	<b>-</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Producing Equipment:</b>																					
Tubing Replacement.....	88700	0.00	0.05	0.15	0.00	0.07	0.00	0.00	0.04	0.02	0.07	0.00	0.03	0.18	0.00	0.10	0.00	0.00	0.06	0.03	0.10
Rods & Pumps.....	59000	0.00	0.03	0.10	0.00	0.05	0.00	0.00	0.02	0.01	0.05	0.00	0.02	0.12	0.00	0.07	0.00	0.00	0.04	0.02	0.07
Pumping Equipment.....	284100	0.00	0.16	0.47	0.00	0.22	0.00	0.00	0.12	0.06	0.22	0.00	0.10	0.57	0.00	0.32	0.00	0.00	0.18	0.08	0.32
<b>Subtotal or Index..</b>	<b>431,800</b>	<b>-</b>	<b>0.24</b>	<b>0.71</b>	<b>0.00</b>	<b>0.34</b>	<b>0.00</b>	<b>0.00</b>	<b>0.18</b>	<b>0.08</b>	<b>0.33</b>	<b>-</b>	<b>0.15</b>	<b>0.87</b>	<b>0.00</b>	<b>0.49</b>	<b>0.00</b>	<b>0.00</b>	<b>0.27</b>	<b>0.12</b>	<b>0.49</b>
<b>Injection Wells</b>																					
<b>Normal Daily Expense:</b>	<b>11</b>	<b>84</b>	<b>86</b>	<b>92</b>	<b>89</b>	<b>92</b>	<b>92</b>	<b>91</b>	<b>93</b>	<b>94</b>	<b>98</b>	<b>85</b>	<b>86</b>	<b>92</b>	<b>89</b>	<b>92</b>	<b>92</b>	<b>91</b>	<b>93</b>	<b>94</b>	<b>98</b>
Supervision and Overhead..	47700	1.29	1.16	1.21	1.17	1.15	1.13	1.01	0.93	0.88	0.89	1.37	1.40	1.47	1.42	1.65	1.44	1.35	1.39	1.30	1.32
Labor (pumper).....	51800	1.40	1.26	1.31	1.27	1.25	1.23	1.09	1.01	0.96	0.97	1.49	1.52	1.60	1.54	1.79	1.57	1.47	1.51	1.41	1.44
Chemicals.....	6700	0.18	0.16	0.17	0.16	0.16	0.16	0.14	0.13	0.12	0.13	0.19	0.20	0.21	0.20	0.23	0.20	0.19	0.19	0.18	0.19
Fuel, Power & Water.....	120000	3.25	2.92	3.04	2.93	2.89	2.84	2.53	2.34	2.21	2.24	3.44	3.51	3.71	3.56	4.15	3.63	3.39	3.49	3.26	3.33
Operative Supplies.....	6400	0.17	0.16	0.16	0.16	0.15	0.15	0.14	0.12	0.12	0.12	0.18	0.19	0.20	0.19	0.22	0.19	0.18	0.19	0.17	0.18
<b>Subtotal or Index....</b>	<b>232,600</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>5</b>	<b>5</b>	<b>4</b>	<b>4</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>8</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>6</b>	<b>6</b>
<b>Surface Maintenance, Repair &amp; Services:</b>																					
Labor (roustabout).....	26700	0.72	0.65	0.68	0.65	0.64	0.63	0.56	0.52	0.49	0.50	0.77	0.78	0.83	0.79	0.92	0.81	0.76	0.78	0.73	0.74
Supplies & Services.....	37600	1.02	0.91	0.95	0.92	0.91	0.89	0.79	0.73	0.69	0.70	1.08	1.10	1.16	1.12	1.30	1.14	1.06	1.09	1.02	1.04
Equipment Usage.....	14400	0.39	0.35	0.36	0.35	0.35	0.34	0.30	0.28	0.27	0.27	0.41	0.42	0.45	0.43	0.50	0.44	0.41	0.42	0.39	0.40
Other.....	4400	0.12	0.11	0.11	0.11	0.11	0.10	0.09	0.09	0.08	0.08	0.13	0.13	0.14	0.13	0.15	0.13	0.12	0.13	0.12	0.12
<b>Subtotal or Index....</b>	<b>83,100</b>	<b>2.25</b>	<b>2.02</b>	<b>2.10</b>	<b>2.03</b>	<b>2.00</b>	<b>1.97</b>	<b>1.75</b>	<b>1.62</b>	<b>1.53</b>	<b>1.55</b>	<b>2.38</b>	<b>2.43</b>	<b>2.57</b>	<b>2.47</b>	<b>2.88</b>	<b>2.51</b>	<b>2.35</b>	<b>2.42</b>	<b>2.26</b>	<b>2.31</b>
<b>Subsurface Maintenance, Repair &amp; Services:</b>																					
Workover Rig Services.....	46400	1.26	1.13	1.17	1.13	1.12	1.10	0.98	0.90	0.86	0.87	1.33	1.36	1.43	1.38	1.61	1.40	1.31	1.35	1.26	1.29
Remedial Services.....	13900	0.38	0.34	0.35	0.34	0.34	0.33	0.29	0.27	0.26	0.26	0.40	0.41	0.43	0.41	0.48	0.42	0.39	0.40	0.38	0.39
Equipment Repair.....	11200	0.30	0.27	0.28	0.27	0.27	0.27	0.24	0.22	0.21	0.21	0.32	0.33	0.35	0.33	0.39	0.34	0.32	0.33	0.30	0.31
Other.....	9100	0.25	0.22	0.23	0.22	0.22	0.22	0.19	0.18	0.17	0.17	0.26	0.27	0.28	0.27	0.31	0.28	0.26	0.26	0.25	0.25
<b>Subtotal or Index....</b>	<b>80,600</b>	<b>2.18</b>	<b>1.96</b>	<b>2.04</b>	<b>1.97</b>	<b>1.94</b>	<b>1.91</b>	<b>1.70</b>	<b>1.57</b>	<b>1.49</b>	<b>1.51</b>	<b>2.31</b>	<b>2.36</b>	<b>2.49</b>	<b>2.39</b>	<b>2.79</b>	<b>2.44</b>	<b>2.28</b>	<b>2.34</b>	<b>2.19</b>	<b>2.24</b>
<b>TOTAL</b>	<b>1,264,800</b>	<b>11</b>	<b>10</b>	<b>11</b>	<b>10</b>	<b>10</b>	<b>9</b>	<b>8</b>	<b>8</b>	<b>7</b>	<b>8</b>	<b>11</b>	<b>12</b>	<b>14</b>	<b>12</b>	<b>15</b>	<b>12</b>	<b>11</b>	<b>12</b>	<b>11</b>	<b>12</b>

**Appendix 8: Total Production Cost Result per simulation scenario (Ego and Orihuela, 2014; Morocho, 2016).**

Table A720: Appendix 8 (Ego and Orihuela, 2014; Morocho, 2016).

$\beta_0$	$\beta_q$	$\beta_1$	$\beta_2$	$\beta_3$
-15.46164	1.055201	0.011224	0.935205	0.053571

**SCENARIO 1**

Year	Q(t) [bbt]	W1	W2	W3	LN(q)	LN(W1)	LN(W2)	LN(W3)	ln(PC)	PC
2019	4,445,415	32,275,014	87,300,219	11,295,520	15.31	17.29	18.28	16.24	18.85	154,371,383
2020	4,448,504	32,323,618	88,070,282	11,737,285	15.31	17.29	18.29	16.28	18.87	156,081,701
2021	4,474,111	56,289,535	95,211,772	14,168,561	15.31	17.85	18.37	16.47	18.96	171,685,397
2022	4,472,271	43,814,687	92,038,089	11,981,902	15.31	17.60	18.34	16.30	18.92	164,306,430
2023	4,510,813	39,964,665	97,320,756	13,517,010	15.32	17.50	18.39	16.42	18.98	175,634,871
2024	4,577,612	48,096,722	100,893,406	13,013,560	15.34	17.69	18.43	16.38	19.03	184,505,734
2025	4,629,818	51,357,145	102,187,519	13,179,844	15.35	17.75	18.44	16.39	19.06	189,233,572
2026	4,695,455	50,692,256	106,524,719	14,518,367	15.36	17.74	18.48	16.49	19.12	200,686,937
2027	4,751,389	51,924,242	110,356,076	14,689,255	15.37	17.77	18.52	16.50	19.16	210,226,167
2028	4,792,338	53,580,807	117,069,802	16,587,276	15.38	17.80	18.58	16.62	19.23	225,728,467
										1,832,460,658

**SCENARIO 2**

Year	Q(t) [bbt]	W1	W2	W3	LN(q)	LN(W1)	LN(W2)	LN(W3)	ln(PC)	PC
2019	4,426,997	31,985,248	70,980,296	11,194,108	15.30	17.28	18.08	16.23	18.66	126,577,482
2020	4,581,753	35,796,746	70,865,074	12,498,500	15.34	17.39	18.08	16.34	18.70	131,994,537
2021	4,678,959	64,708,633	74,042,131	15,563,822	15.36	17.99	18.12	16.56	18.78	143,211,653
2022	4,943,142	60,158,242	99,849,507	14,696,528	15.41	17.91	18.42	16.50	19.11	199,945,585
2023	5,046,082	56,745,981	104,739,057	16,934,872	15.43	17.85	18.47	16.64	19.19	215,173,153
2024	5,068,146	65,632,500	98,281,346	15,936,870	15.44	18.00	18.40	16.58	19.13	203,346,539
2025	5,130,183	69,737,937	107,100,982	16,129,330	15.45	18.06	18.49	16.60	19.22	223,507,076
2026	5,034,486	63,144,695	107,030,588	16,657,026	15.43	17.96	18.49	16.63	19.21	219,108,883
2027	5,199,862	67,982,277	107,247,420	17,483,671	15.46	18.03	18.49	16.68	19.24	227,918,825
2028	5,163,412	67,099,155	106,857,710	19,153,604	15.46	18.02	18.49	16.77	19.24	226,535,651
										1,917,319,384

SCENARIO 3

Year	q(t) [bbi]	ω1	ω2	ω3	LN(q)	LN(W1)	LN(W2)	LN(W3)	ln(PC)	PC
2019	4,426,997	31,985,248	86,159,272	11,194,108	15.30	17.28	18.27	16.23	18.84	151,728,528
2020	4,935,186	44,777,957	120,814,295	14,517,570	15.41	17.62	18.61	16.49	19.29	237,606,574
2021	4,922,863	75,594,251	127,371,070	17,225,098	15.41	18.14	18.66	16.66	19.35	252,760,510
2022	4,431,075	42,946,215	89,387,877	11,744,403	15.30	17.58	18.31	16.28	18.88	158,118,809
2023	5,022,853	55,421,781	134,574,225	16,786,548	15.43	17.83	18.72	16.64	19.42	270,491,712
2024	4,337,312	40,969,548	85,089,824	11,581,507	15.28	17.53	18.26	16.26	18.81	147,439,349
2025	4,041,725	30,733,482	65,756,865	9,713,230	15.21	17.24	18.00	16.09	18.48	106,191,436
2026	4,470,831	27,257,477	91,553,319	13,101,412	15.31	17.12	18.33	16.39	18.91	163,352,800
2027	4,357,190	27,257,477	84,262,186	12,233,019	15.29	17.12	18.25	16.32	18.80	146,563,536
2028	4,021,847	27,257,477	66,679,556	11,258,608	15.21	17.12	18.02	16.24	18.50	107,730,714
										<b>1,741,983,967</b>

SCENARIO 4

Year	Q(t) [bbi]	W1	W2	W3	LN(q)	LN(W1)	LN(W2)	LN(W3)	ln(PC)	PC
2019	4,367,450	31,048,435	82,515,637	10,738,407	15.29	17.25	18.23	16.19	18.78	143,284,655
2020	4,124,454	25,591,979	68,777,641	10,131,735	15.23	17.06	18.05	16.13	18.54	113,163,495
2021	4,076,973	41,836,034	70,211,182	11,463,572	15.22	17.55	18.07	16.25	18.56	115,357,974
2022	4,074,009	32,775,532	67,771,740	9,685,876	15.22	17.31	18.03	16.09	18.52	110,215,257
2023	3,998,149	27,257,477	65,383,696	10,243,482	15.20	17.12	18.00	16.14	18.47	104,583,195
2024	3,969,428	30,239,596	63,127,281	9,389,119	15.19	17.22	17.96	16.06	18.42	100,086,114
2025	3,812,209	27,221,997	53,377,912	8,360,310	15.15	17.12	17.79	15.94	18.21	81,377,881
2026	3,675,814	22,184,009	46,460,338	8,086,332	15.12	16.91	17.65	15.91	18.04	68,495,733
2027	3,595,016	20,029,898	42,541,827	7,483,944	15.10	16.81	17.57	15.83	17.93	61,290,364
2028	3,561,400	19,469,300	42,345,105	8,074,184	15.09	16.78	17.56	15.90	17.92	60,650,188
										<b>958,504,856</b>

SCENARIO 5

Year	Q(t) [bbi]	W1	W2	W3	LN(q)	LN(W1)	LN(W2)	LN(W3)	ln(PC)	PC
2019	4,457,867	33,120,334	88,081,134	11,364,081	15.31	17.32	18.29	16.25	18.87	156,218,489
2020	4,477,464	33,434,811	89,874,776	11,902,725	15.31	17.33	18.31	16.29	18.89	160,344,377
2021	4,450,235	55,643,456	93,618,763	14,005,938	15.31	17.83	18.35	16.45	18.94	167,920,408
2022	4,434,894	43,026,711	89,638,162	11,766,416	15.31	17.58	18.31	16.28	18.88	158,696,224
2023	4,695,455	45,623,031	110,163,666	14,696,006	15.36	17.64	18.52	16.50	19.15	206,981,348
2024	4,406,433	43,059,952	89,503,240	11,993,428	15.30	17.58	18.31	16.30	18.88	157,562,467
2025	4,295,968	40,696,431	80,683,544	11,211,911	15.27	17.52	18.21	16.23	18.75	138,624,701
2026	4,307,605	39,138,990	81,254,736	12,071,756	15.28	17.48	18.21	16.31	18.76	140,434,682
2027	4,163,996	34,531,012	72,597,649	11,029,232	15.24	17.36	18.10	16.22	18.61	121,190,354
2028	4,126,730	33,804,028	72,825,486	11,983,976	15.23	17.34	18.10	16.30	18.61	120,906,271
										<b>1,528,879,322</b>

**Appendix 9: Calculation of Profit Margin Ratios per simulation scenario.**

Table A821: Appendix 9 (Aboody, 1996; Gallagher and Andrew, 2007; Iskakov and Yilmaz, 2015; Mandal and Goswami, 2010).

<b>Operating Income</b>	<b>1,721,743,944.75</b>	<b>Operating Profit Margin</b>	<b>48%</b>
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SCENARIO 1									
Year	Q	COP	Operating Income Variation	Operating Income	PC	$D_2$	$D_1$	$D_{32}$	$D_{31}$
2019	4,445,415	71.11	53%	161,748,619	154,371,383	3149	50	85	0
2020	4,448,504	71.26	-1%	160,906,225	156,081,701	3172	50	86	1
2021	4,474,111	72.46	-5%	152,530,953	171,685,397	3387	86	92	6
2022	4,472,271	72.38	4%	159,388,474	164,306,430	3277	67	89	0
2023	4,510,813	74.20	0%	159,049,851	175,634,871	3402	60	92	3
2024	4,577,612	77.35	7%	169,557,922	184,505,734	3419	70	92	0
2025	4,629,818	79.81	6%	180,268,411	189,233,572	3382	73	91	0
2026	4,695,455	82.91	5%	188,590,031	200,686,937	3425	70	93	2
2027	4,751,389	85.54	4%	196,223,474	210,226,167	3464	70	94	1
2028	4,792,338	87.47	-1%	193,479,984	225,728,467	3612	71	98	4

<b>Operating Income</b>	<b>2,737,067,591.07</b>	<b>Operating Profit Margin</b>	<b>59%</b>
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SCENARIO 2									
Year	Q	COP	Operating Income Variation	Operating Income	PC	$D_2$	$D_1$	$D_{32}$	$D_{31}$
2019	4,426,997	70.24	75%	184,386,883	126,577,482	3136	50	85	0
2020	4,581,753	77.54	21%	223,284,280	131,994,537	3266	52	86	1
2021	4,678,959	82.13	8%	241,057,348	143,211,653	3542	90	92	6
2022	4,943,142	94.59	11%	267,615,016	199,945,585	3622	75	89	0
2023	5,046,082	99.44	7%	286,624,667	215,173,153	3806	68	92	3
2024	5,068,146	100.48	7%	305,919,938	203,346,539	3786	78	92	0
2025	5,130,183	103.41	0%	307,004,485	223,507,076	3748	81	91	0
2026	5,034,486	98.90	-9%	278,782,409	219,108,883	3673	76	93	2
2027	5,199,862	106.70	17%	326,887,876	227,918,825	3790	77	94	1
2028	5,163,412	104.98	-3%	315,504,689	226,535,651	3892	77	98	4

<b>Operating Income</b>	<b>1,618,381,217.75</b>	<b>Operating Profit Margin</b>	<b>48%</b>
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SCENARIO 3									
Year	Q	COP	Operating Income Variation	Operating Income	PC	$D_2$	$D_1$	$D_{32}$	$D_{31}$
2019	4,426,997	70.24	51%	159,235,837	151,728,528	3136	50	85	0
2020	4,935,186	94.21	43%	227,349,342	237,606,574	3518	56	86	1
2021	4,922,863	93.63	-8%	208,173,082	252,760,510	3727	95	92	6
2022	4,431,075	70.44	-26%	153,984,462	158,118,809	3247	67	89	0
2023	5,022,853	98.35	45%	223,492,944	270,491,712	3788	67	92	3
2024	4,337,312	66.01	-38%	138,877,892	147,439,349	3240	67	92	0
2025	4,041,725	52.07	-25%	104,263,735	106,191,436	2953	64	91	0
2026	4,470,831	72.31	53%	159,934,213	163,352,800	3262	67	93	2
2027	4,357,190	66.95	-9%	145,151,118	146,563,536	3176	65	94	1
2028	4,021,847	51.13	-33%	97,918,593	107,730,714	3031	60	98	4



<b>Operating Income</b>	<b>898,803,149.19</b>	<b>Operating Profit Margin</b>	<b>48%</b>
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SCENARIO 4									
Year	Q	COP	Operating Income Variation	Operating Income	PC	$D_2$	$D_1$	$D_{32}$	$D_{31}$
2019	4,367,450	67.43	43%	151,230,473	143,284,655	3094	50	84	0
2020	4,124,454	55.97	-22%	117,693,553	113,163,495	2941	47	86	2
2021	4,076,973	53.73	-12%	103,710,710	115,357,974	3087	79	92	6
2022	4,074,009	53.59	4%	108,124,750	110,215,257	2985	62	89	0
2023	3,998,149	50.02	-12%	95,385,343	104,583,195	3016	54	92	3
2024	3,969,428	48.66	-2%	93,068,659	100,086,114	2965	61	92	0
2025	3,812,209	41.25	-18%	75,856,974	81,377,881	2785	61	91	0
2026	3,675,814	34.81	-22%	59,465,772	68,495,733	2682	55	93	2
2027	3,595,016	31.00	-16%	50,157,864	61,290,364	2621	53	94	1
2028	3,561,400	29.42	-12%	44,109,052	60,650,188	2684	53	98	4

<b>Operating Income</b>	<b>1,466,874,803.66</b>	<b>Operating Profit Margin</b>	<b>49%</b>
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SCENARIO 5									
Year	Q	COP	Operating Income Variation	Operating Income	PC	$D_2$	$D_1$	$D_{32}$	$D_{31}$
2019	4,457,867	71.70	55%	163,405,214	156,218,489	3158	51	85	0
2020	4,477,464	72.62	1%	164,823,091	160,344,377	3192	51	86	1
2021	4,450,235	71.34	-9%	149,554,130	167,920,408	3369	86	92	6
2022	4,434,894	70.62	3%	154,474,701	158,696,224	3250	67	89	0
2023	4,695,455	82.91	18%	182,295,620	206,981,348	3542	63	92	3
2024	4,406,433	69.27	-19%	147,683,515	157,562,467	3291	68	92	0
2025	4,295,968	64.06	-8%	136,585,880	138,624,701	3139	68	91	0
2026	4,307,605	64.61	1%	137,885,600	140,434,682	3142	65	93	2
2027	4,163,996	57.84	-13%	119,645,930	121,190,354	3035	62	94	1
2028	4,126,730	56.08	-8%	110,521,124	120,906,271	3110	62	98	4

## Appendix 10: Numerical detail of Operative functions for Primary Recovery.

Table A922: Appendix 10 (Agarwal, Sharma and Mathew, 2016; Lind, Marchal and Mason, 2004).

FACTOR									
A	Development and Equipment of Primary Recovery								
B	Operation of Primary Recovery								
IT	Activities	SCE 1	SCE 2	SCE 3	SCE 4	SCE 5	Average	Average Aggregated	% Average Aggregated
A5	Drilling Rig	121,248	140,526	116,645	84,955	110,259	114,726.77	114,726.77	17%
A9	Stimulation (Hydraulic Fracturing)	92,044	106,678	88,549	64,492	83,701	87,092.83	201,819.59	30%
A6	Cementing	89,214	103,398	85,827	62,510	81,128	84,415.34	286,234.93	42%
A7	Drilling Fluids	77,089	89,346	74,163	54,014	70,103	72,943.03	359,177.96	53%
A1	Casing and Tubing	44,489	51,562	42,800	31,172	40,457	42,096.11	401,274.07	59%
A10	Facilities (Platforms, roads...)	44,332	51,380	42,649	31,062	40,314	41,947.36	443,221.43	65%
A3	Pumps	38,869	45,049	37,393	27,234	35,346	36,778.31	479,999.74	71%
A2	Bits	30,969	35,893	29,794	21,699	28,163	29,303.65	509,303.39	75%
A4	Wireline Services	30,341	35,164	29,189	21,259	27,591	28,708.65	538,012.04	79%
A8	Well Testing	26,921	31,202	25,899	18,863	24,481	25,473.35	563,485.39	83%
A18	Electrification	26,489	30,701	25,483	18,560	24,088	25,064.29	588,549.68	87%
A11	Flowlines	19,179	22,228	18,451	13,438	17,441	18,147.44	606,697.12	89%
A15	Storage Tanks	14,258	16,525	13,717	9,991	12,966	13,491.58	620,188.70	91%
B5	Fuel, Power & Water	11,743	13,610	11,297	8,228	10,679	11,111.59	631,300.29	93%
A16	Disposal System	10,658	12,353	10,254	7,468	9,692	10,085.22	641,385.50	94%
A12	Manifold	7,275	8,431	6,998	5,097	6,615	6,883.38	648,268.88	96%
A14	Test Separator	5,074	5,880	4,881	3,555	4,614	4,800.89	653,069.77	96%
A17	LACT Unit	4,960	5,748	4,772	3,475	4,510	4,693.05	657,762.82	97%
A13	Producing Separator	4,366	5,061	4,201	3,059	3,971	4,131.52	661,894.34	98%
B2	Labor (pumper)	4,166	4,828	4,008	2,919	3,788	3,941.86	665,836.20	98%
B1	Supervision and Overhead	3,443	3,990	3,312	2,412	3,131	3,257.61	669,093.81	99%
B10	Workover Rig Services	2,688	3,116	2,586	1,884	2,445	2,543.62	671,637.43	99%
B12	Equipment Repair	1,776	2,059	1,709	1,245	1,615	1,680.87	673,318.30	99%
B7	Labor (roustabout)	1,698	1,968	1,633	1,190	1,544	1,606.49	674,924.79	99%
B8	Supplies & Services	1,100	1,275	1,059	771	1,001	1,041.25	675,966.04	100%
B3	Auto Usage	1,069	1,239	1,028	749	972	1,011.50	676,977.54	100%
B4	Chemicals	582	674	560	408	529	550.37	677,527.91	100%
B9	Equipment Usage	519	601	499	363	472	490.87	678,018.78	100%
B11	Remedial Services	393	455	378	275	357	371.87	678,390.66	100%
B6	Operative Supplies	283	328	272	198	257	267.75	678,658.41	100%
B13	Other	79	91	76	55	71	74.37	678,732.78	100%