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The Use of Fuzzy Logic to Assess Sustainability of Oil and Gas Resources (*R/P*): Technical, Economic and Political Perspectives

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ABSTRACT

This work presents, based on fuzzy logic, an equation that combine the impact of both technical and non-technical factors on sustainability of oil and gas. The classical formula for oil and gas sustainability factor (α = R/P) was fuzzified to include a risk factor (β) that takes into account risks associated with economic health and political stability of oil and gas producing countries. This was made possible through the introduction of risk impact factor (γ) and risk impact weight % (w) into the overall risk factor (β). Results showed that economic factors: oil-revenue dependence; public debt; and institutional structure, all impact oil and gas sustainability. The level of economic diversity was found to play a major role on oil and gas sustainability. It was also shown that political stability should not be overlooked as it could indirectly impact oil and gas sustainability. This is especially true for young political regimes due to lack of long-term clear (institutional) vision; proper strategic planning; in-house knowledge and experience; and decision-making flexibility. A hypothetical case study was presented to show how our fuzzified formula works. Results showed that "sustainability" factor (α) dropped by 45.1% when including economic health and political stability risk factors.

Keywords: Fuzzy Logic, Oil and Gas Sustainability, Volumetric Reserves Estimation, Political Stability
JEL Classification: JEL Q40

1. BACKGROUND AND PRIOR WORK

The 20th century has been highly impacted by the oil and gas revolution. In fact, oil and gas has affected and improved our lives more than any other natural resource throughout mankind history. However, this positive side of the oil and gas industry is overshadowed by the globally uneven and scarce distribution of this valuable resource (oil), where 48.3% of this natural resource is in the Middle East (BP Statistical Review of World Energy, 2021).

Over the past century, many oil-producing countries have thrived due to the vast abundancy of oil and gas and are expected to continue their prosperity for decades to come. Iledare and Pulsipher (1999) investigated trends in recoverable oil reserves and performance measures in the global upstream petroleum industry for evidence that agrees with, or disregards, the notion that the world is running out of oil. Their empirical analysis indicates a growing world abundance of crude oil and discards the imminent worldwide petroleum-exhaustion theory.

One of the most widely used metrics for oil and gas producing countries' wealth and prosperity is "sustainability" of oil and gas resources. This "sustainability" of oil and gas resources is measured by the number of years a producing country is expected to economically extract these resources from the ground, while increasing or at least maintaining production rates. Sustainability is referred to in the literature as life expectancy (or age) of oil and gas resources (Garb, 1985; Gajdica and Byrne, 2020; Thompson and Wright, 1984; Feygin and Satkin, 2004). Sustainability of oil and gas resource is defined in terms of both proven reserves and production as follows:

$$\alpha = \frac{R}{P} \quad (1)$$

where;
(α) is resource (oil or gas) sustainability (years).
(R) is the proven (oil or gas) reserves (bbl or MMscf).
(P) is the (oil or gas) production (bbl/year or MMscf per year).

For example, a country having a proven oil reserve (R) of 100 billion barrels and produces (P) 1 billion barrels per year is expected to have a sustainability factor (α) of 100 years. Therefore, in order to calculate the sustainability of oil and gas (α), one must first estimate the proven oil and gas reserves (R) and measure their respective production rates (P).

Two methods are currently used for proven reserves estimation: volumetric method and material-balance method. Volumetric method calculates the volume of oil and gas (stock tank barrels; STB) based on the physical properties of the reservoir rocks and fluids. Namely, this method makes use of the following parameters for reservoir-volume estimation:
1. Size of the reservoir (height (h) and area (A)).
2. Physical properties of the reservoir rocks (porosity (ϕ) and water saturation (S_w)).
3. Physical properties of the reservoir fluids (formation oil factor (B_o)).

Once these parameters are determined (estimated), proven oil reserve (R) is calculated as follows:

$$R = \frac{7758\varphi(1 - S_w)Ah}{B_o} \quad (2)$$

where;
(R) is the proven oil reserves (STB).
(ϕ) is the reservoir porosity.
(S_w) is the reservoir water saturation.
(A) is the reservoir area (ft^2).
(h) is the reservoir height (ft).
(B_o) is the oil-formation factor (reservoir barrel/stock tank barrel).

Equation (2) is used only for calculating proven oil reserves. Similar equations exist for dissolved-gas, and free-gas, reservoir-reserves calculations (Meyer, 1978; Sustakoski and Morton-Thompson, 1992).

While this method is widely used for proven oil- and gas-reserves estimation, it should only be used in the early life of the property and should serve as a first-hand estimate due to the technical limitations imposed on it (Lee and Sidle, 2010). Some of the technical limitations that may effectively hinder the use of the volumetric method include, but not limited to, the lack of accurate and reliable reservoir size and reservoir rocks and fluids physical-properties data. In addition, measurements of reservoir properties are normally conducted under laboratory conditions, which do not reflect real field conditions (Al-Bazali et al., 2007).

Material-balance method, nevertheless, alleviates most of the technical problems encountered with using the volumetric method. Material-balance method is more complex and accurate than the volumetric method and provides an estimate of reserves over time under certain reservoir conditions (Walsh, 1995; Xin et al., 2002). This method requires the knowledge of PVT (pressure, volume, and temperature) data of the reservoir fluids as well as an accurate pressure history of the reservoir.

Several attempts have been made to improve the estimation of oil and gas proven reserves. Demirmen (2007) has placed a great emphasis on conventional oil- and gas-reserves evaluation at the interpretation stage, in which estimation errors cause a profound economic impact. Harrell et al. (2004) discussed the most common errors associated with reserves estimations and presented some guidelines that could decrease the occurrence of such errors. Ojo and Osisanya (2006) introduced a time variable into the classical material balance equation (MBE) and combined the outcome with the theory of pressure-transient analysis, the cumulative-production history of the reservoir and readily-available PVT data of the reservoir fluids. They were able to determine not only the original reserves in place, but also the average reservoir pressure decline history. Shahamat and Clarkson (2018) showed that both gas production and water production/injection can have a significant impact on the estimated original-in-place hydrocarbon volumes. Penuela et al. (2001) presented a new material-balance equation for naturally fractured reservoirs using an original mathematical model that considers an initially-undersaturated black oil fluid in a porous medium composed of interdependent matrix and fracture systems. Jiao et al. (2017) proposed a new thought to define rock-elastic energy and water-influx energy using the linear relationship of cumulative production, which simplifies the material-balance equation and converts to a multivariate-nonlinear equation. Cockcroft et al. (1989) investigated the impact of wettability on oil reserves and showed that changes in wettability could greatly reduce the volume of oil in place. Ampomah et al. (2016) presented a field scale reservoir evaluation and uncertainty analysis of hydrocarbon-reserves estimation for the Upper Morrow B reservoir of the Farnsworth Unit (FWU), Ochiltree County, Texas. They showed that the degree of uncertainty in volumetric-reserves estimation for hydrocarbon in place is controlled in larger order by the geological complexity of the reservoir and quality of available geologic data.

As indicated by equation (1), sustainability factor (α) depends mainly on technical data such as proven reserves estimates and production rates. This explains why nearly all past work have focused on improving the understanding and application of equation (1), in order to enhance our ability to estimate oil and gas reserves. While this may have been acceptable over the past century, due to the abundancy of oil and gas resources, equation (1) needs to be modified to reflect the new challenges of the new century. We believe that one should take into account, among other factors, the overall economy health; political stability; environmental concerns; and competition from other energy resources when analyzing the "sustainability" of oil and gas pertaining to both producing countries as well as exploration and production (E&P) companies.

Relaying only on technical data for reserves estimation may prove to be risky and erroneous. Technical data includes reservoir properties and conditions such as porosity; water saturation; oil formation factor; reservoir size; reservoir pressure; reservoir temperature; and production rates.

This paper applies the concept of fuzzy logic to combine the impact of both technical and non-technical factors on the sustainability factor (α) and reserves estimations of oil and gas. This was made possible by modifying equation (1) to include the impact of non-technical factors as explained next.

2. METHODOLOGY USING FUZZY LOGIC

From equation (1), one might argue that the only factors controlling oil and gas sustainability is reserves (R) and production (P) rates. That is why many oil and gas producing countries have invested heavily in exploration and production (E&P) technologies to improve their reserves (R) and production rates (P). While this approach has worked well in the past, one cannot ignore economic (macro and micro) factors that could play a major role in determining oil and gas sustainability. These economic factors include operational economics (specific to oil and gas exploration and production operations) as well as overall economic health and institutional quality (governance) of the host country.

Operational economics include, but not limited to, production capacity; capital and operating costs; depreciation and depletion; and incurred taxes. Although all estimates of oil and gas reserves require economic assessments that consider operational economics (financial results), such assessments are purely "operation" specific and do not reflect the true sustainability of oil and gas resources. We believe that true sustainability of oil and gas resources could also be profoundly impacted by the overall health of the economy of the host country.

Equally important, political stability; social reforms; competition from other energy sources; local-energy consumption; and environmental regulations (domestic and global) could have deep impacts (risks) on oil and gas "sustainability." Therefore, equation (1) has been corrected to reflect the effects of other factors on the sustainability of oil and gas resources as shown in equation (3):

$$\alpha = \frac{R}{P} e^{-\beta} \tag{3}$$

where (β) is a risk factor beta that reflects the following risk types:
1. Oil and gas reserves and production risk
2. Operational economics risk
3. Host-country's economy-health risk
4. Political-stability risk
5. Social-reforms risk
6. Competition from other energy sources risk
7. Local energy-consumption risk
8. Environmental-regulations risk
9. Tax-related risk
10. Other risks.

A zero value for (β) indicates "no risks" involved, and that makes the sustainability value (α) equals to 100% of (R/P). However, a value of (β) greater than zero means that the sustainability of oil and gas is at risk; and it may be less than the expected 100% (R/P). Deviation from 100% (R/P), naturally, depends on the amount of risks involved, expressed by (β), as shown in Figure 1.

Recognizing that the impact of each risk type, as mentioned above (from 1 to 10), on the value of (β) may differ, we are proposing a formula that takes into account a risk-impact factor and a risk-impact weight for each risk type on the value of (β), as follows:

$$\beta = \sum_{i}^{n} \gamma w \tag{4}$$

where;
(γ) is the risk-impact factor for each risk type.
(*w*) is the risk-impact weight % for each risk type.

While it is not difficult to pinpoint risk types that impact oil and gas sustainability for oil and gas producing (exporting) countries, it is quite problematic to assess their risk-impact factor (γ) and risk-impact weight (*w*). We believe that risk-impact factor (γ) and risk-impact weight (*w*) is different for each oil and gas producing country; and may differ over time for the same country. Additionally, this assessment work requires lots of effort and resources; and a positive cooperation from oil and gas producing countries, many of which do not disclose such data to the public due to national-security or socio-political considerations.

In our proposed work, we will purposely limit our discussion to (3) risk types: oil and gas reserves and production risk; host-country's economy-health risk; and political-stability risk. We have chosen these three types of risks because they are relevant to all oil-producing countries and companies; and could noticeably affect their oil and gas sustainability. Moreover, adequate published data is available to assess these risk types. Future work will include all types of the other mentioned risks.

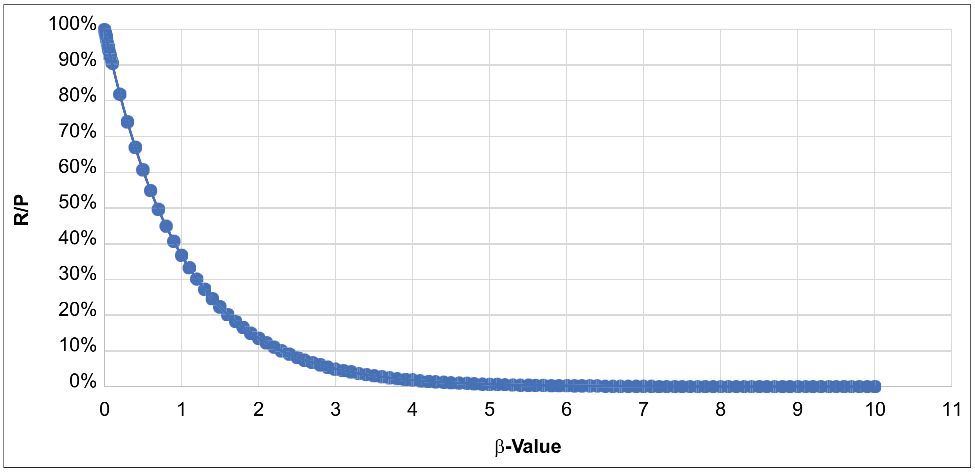
In our proposed methodology, a risk-impact weight (%) for each risk type is assigned as shown in Table 1. As seen in Table 1, more weight is given to oil and gas reserves and production risk to reflect its importance in maintaining oil and gas sustainability; while assigning equal risk-impact weights (%) for host-country's economy-health risk as well as political-stability risk. It is prudent to show the influence of risk-impact weight (%) variations on each factor using a sensitivity-analysis technique (spider diagram).

The next step in our proposed work is to qualitatively categorize and assign a risk-impact factor (γ) for each risk type. For example, oil and gas reserves and production risk type is considered in three categories: reliable estimates; 50%-reliability estimates; and non-reliable estimates.

Table 1: Risk types and their associated risk weights (w) %

Risk Type	Risk Weight (w) %
Oil and gas reserves and production risk	60
Host country's economy health risk	20
Political stability risk	20

Figure 1: Expected reduction in (R/P) as a function of the risk factor (□)



Host-country's economy-health risk type is classified into three categories: single-source economy; partially diversified economy; and well-diversified economy. Finally, political-stability risk type is divided into three classes: very stable; quasi stable; and unstable.

The numerical value for the risk-impact factor (γ) goes from [0] to [1] and is selected based on a qualitative assessment of the risk type, so that a (γ) value of zero carries no risk while a (γ) value of [1] carries maximum risk. Tables 2-4 show categories of each risk type, and proposed (γ) values for each category: oil and gas reserves and production risk; host-country's economy-health risk; and political-stability risk, respectively.

In the future, we plan to expand the categories of each risk type and improve the numerical values assigned to the risk-impact factor (γ) to better reflect their effects on risk factor (β) and sustainability factor of oil and gas resources (α). The following example illustrates the use of equations (3) and (4).

Country name - (XYZ)

- (R) - reserves of 100 billion barrels of oil
- (P) - rate of 1 billion barrels of oil per year
- Oil and gas reserves and production estimate - non-reliable
- Health of economy - single source
- Political stability - unstable

If we apply equation (1) to calculate the sustainability factor (α) without considering any type of risk, as proposed by this paper, we would obtain a sustainability factor (α) of 100 years.

However, if we follow our proposed theory and methodology, as explained above, the sustainability factor (α) will be reduced by 67%; to 37 years only, as shown below.

$\beta = 1.0*60\% + 1.0*20\% + 1.0*20\% = 1.0$

$\alpha = 100 \text{ years} * EXP(-1) = 100 \text{ years}*(0.3679) = 36.79 \text{ years}$

So we see that the sustainability factor (α) of oil and gas resources in this example, with assumed full (high) risk in all (3) types, is 36.79 years. That is quite different from the answer we obtained when using equation (1), where all risk types were ignored. More analysis and application of our proposed theory will be explained next.

Table 2: Assigned risk-impact factor (γ) for oil and gas reserves and production risk type

Reliable Estimates	50% Estimate Reliability	Non-Reliable Estimates
0	0.5	1

Table 3: Assigned risk-impact factor (γ) for host-country's economy-health risk type

Single-source Economy	Partially Diversified Economy	Well-Diversified Economy
1	0.5	0

Table 4: Assigned risk-impact factor (γ) for political-stability risk type

Very Stable	Quasi Stable	Unstable
0	0.5	1

3. DISCUSSION AND ANALYSES

The discussion will be limited to (3) risk types: oil and gas reserves and production risk; host-country's economy-health risk; and political-stability risk. We have chosen these three types of risks because they are relevant to all oil producing countries and companies; and could noticeably affect their oil and gas sustainability. Moreover, adequate published data is available to assess these risk types.

3.1. Oil and Gas Reserves and Production Risk

Reserves estimation is one of the most important tasks facing oil-producing and exporting countries since their revenues and economies depend mainly on it. It is defined as a technical procedure by which economically recoverable oil is evaluated from potentially oil-bearing formations. Reserves are classified into various categories, as shown in Figure 2, according to their degree of uncertainty of existence and recovery.

Reserves estimation methodologies fall within three categories: (1) Volumetric calculations, (2) analogy, and (3) performance techniques. Performance techniques mainly include decline-curve analysis; material-balance calculations; and simulation studies. The type and magnitude of risk, associated with reserves-estimation categories, is quite different since each category is conducted at a certain time of the field's life and requires different set of information, data, special handling techniques, and methodologies to establish its respective reserves (Rahimov et al., 2017).

In our paper, we will focus on analyzing the risks associated with reserves estimation using the volumetric method and study its impact on the overall sustainability of oil and gas resources. Future work will investigate the impact of other reserves-estimation methodologies on the sustainability of oil and gas resources.

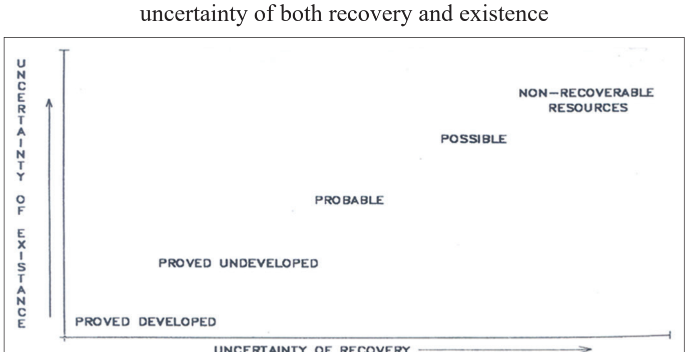
Reserves estimation using the volumetric method requires knowledge of reservoir volume (area and thickness) from maps and petrophysical properties, usually obtained from coring or logging techniques, of the drilled formations. It is normally conducted in the early phases of field exploration and development in order to calculate the amount of oil and gas in place and the corresponding reserves (Rasheed and Kulkarni, 2016). According to equation (2), the following parameters need to be estimated in order to calculate oil reserves in a certain field:

- Reservoir porosity (ϕ)
- Reservoir water (or oil) saturation (S_w or S_o)
- Reservoir volume (area (A) and thickness (h))
- Oil formation factor (B_o).

The degree of uncertainty associated with estimating the above-mentioned parameters produces a probabilistic risk factor (β), shown in equation (3), which could adversely impact the reliability and credibility of estimated oil-reserves volume and thus "sustainability" of oil and gas resources. This probabilistic risk factor (β) is handled through the use of "assigned risk-impact factor (γ)" and "assigned risk-impact weight % (w)", as indicated by equation (4).

The numerical values assigned to risk-impact weight % (w) and risk-impact factor (γ) for oil and gas reserves and production risk type as shown in Tables 1 and 2, respectively, are hypothetical and were selected arbitrarily for the purpose of explaining the use of our theory and proposed methodology. The assignment of risk-impact weights % (w) and risk-impact factors (γ) for all risk types, including but not limited to oil and gas reserves and production risk type, could be reliably improved through the use of expert opinion; past knowledge (analyses); cooperative work by all parties involved; and open access to data and information. A hypothetical case study is presented, in section 3.4, to explore the impact of risks associated with oil and gas reserves and production on the overall sustainability of oil and gas.

Figure 2: Classification of reserves according to their degree of uncertainty of both recovery and existence



3.2. Host-country's Economy-health Risk

Oil and gas revenues are crucial to many, if not almost all, producing and exporting countries and levels of reserves are vital for global macroeconomic stability (Bouri et al., 2020). This is predominantly critical to oil-exporting countries in the MENA region where oil and gas exports directly drive social development and political stability due to what is commonly known as "social contracts" between governing regimes and their citizens. Not all oil-producing (exporting) countries have reaped the benefits of oil wealth, though, as others such as Venezuela and Russia have greatly suffered from the implications of relying on oil. Such implications include, but not limited to, weaker currencies; higher inflation rates; higher interest rates; and slower economic activities and growth.

Oil sustainability and production levels as well as market prices often drive fiscal policies; facilitate finance for mega-projects development; and enable governments to balance their oil-dependent budgets. Breunig and Chia (2015) investigated the effect of high oil prices on sovereign ratings (countries' financial-stability reputation in international financial markets) and found that credit ratings (to measure countries' perceived ability to maintain/repay its debt) – a measure for how cheaply a country can borrow in international debt markets to finance its projects, budget deficits – are negatively affected by lower oil prices based on supply and demand in global markets, and therefore deteriorate oil-producing (exporting) countries' fiscal situation; the health of their economies.

Schneider (2004) argued that oil-price fluctuations affect both supply and demand sides of global trade differently. Higher oil prices make cost of production of goods and services higher for oil importing countries; yet, oil exporting countries ramp up huge oil revenues and profits. This advantage diminishes, however, as the level of global demand for costly goods and services drops, which leads to a reduction in production levels of goods and services and eventually a decrease for oil demand. In addition, diminishing advantage of reaping higher revenues from higher oil prices is further amplified for oil-exporting countries that are mainly (or in some cases fully) dependent on importing non-oil goods. This rising cost of imports, due to higher costs of production and thus lower outputs and trade globally, highlights the importance of globally driven factors in determining a country's economy-health risk that essentially increases over time due to their growing populations.

Hooper (2015) highlighted that oil-rich countries often use their oil reserves as collateral to borrow in international debt markets, which is perceived by credit-rating agencies as good "insurance" (liquid asset with known reserves). This perception, however, proved inconsistent for many oil-exporting countries that are classified as emerging and/or non-diversified economies. Such perception could lead to high economic risk and possible debt default (e.g. Nigeria). Additionally, she argued that empirically the impact of cost of borrowing depends on the country's institutional quality (corporate-governance standards), where increasing levels of reserves (seen as "wealth") could lead to higher debt cost due to higher risk-taking behavior especially in corrupt and politically unstable regimes.

Furthermore, Kretzmann and Nooruddin (2005) found that growing oil production is associated with higher levels of borrowing, which makes oil-producing countries more prone to higher financial shocks. Jimenez-Rodriguez and Sanchez (2005) argued that previous research suggests that oil-price changes impact economic activities; investments, foreign-exchange markets; and inflation. This leads to negative consequences on the health of oil-exporting economies, especially for import-dependent countries on non-oil products.

Apergis and Payne (2014) examined the effect of oil wealth on economic growth and argued that improved institutional quality decreases the "curse" of oil reserves and could positively affect the real performance of the economy. They highlighted that oil abundance drives rent-seeking behavior, which leads to non-productive economies especially in poor-labor countries; develops poor institutional quality in the absence of governance and transparency, especially with the lack of human capital; and potentially fuels corrupt public sectors. Consequently, all of the above hinders real economic growth; weakens the economy; deepens the concern of socio-economic sustainability; and raises the economy-health risk.

Our paper ties together three factors affecting the risk-impact factor (γ) for economy-health risk: oil-revenue dependence (above-average percentage of oil-export revenues vs total GDP), which highlights sustainable economic growth and affects development plans; level of public debt (above financially-acceptable percentage of government borrowing to balance inflated budgets), which affects fiscal sustainability and impacts country ratings; and institutional structure (below internationally-recognized levels of transparency and good governance in the public sector), which hinders human-capital development, increases uncertainty, and deters inward (foreign direct) investments.

For the purpose of this work and as shown in Table 3, a well-diversified (host-country) economy, with all of the aforementioned three factors being favorable, will have an assigned risk-impact factor (γ) for the economy-health risk type of [0]. A partially-diversified (host-country) economy, with at least one of the aforementioned factors being favorable, will have an assigned risk-impact factor (γ) for the economy-health risk type of [0.5]. A single-source (host-country) economy, with all of the aforementioned factors being unfavorable, will have an assigned risk-impact factor (γ) for the economy-health risk type of [1].

3.3. Political-stability Risk

World events have altered how investors measure political stability, and thus a country's risk. Political-science literature as well as economic and investment-risk assessments have attempted to address macro and micro issues. Sottilotta (2013) discussed the limitations of the approaches to political stability evaluation and highlighted the methodologies various international institutions have developed to advance political risk (stability) measurement owed to the globalization of trade and investment.

Foreign direct investment (FDI), for example, is most concerned with how political "changes" (instability) in a country may change the financial outcome of an investment. This, naturally, differs enormously across multinational companies/investors, as their own definition of what is "good change" vs. "bad change" – typically depending on their nationality; home-country power; and other factors – differs, which leads to absence of transparency in the areas of both political-stability (instability) assessments as well as country-risk (economic and otherwise) analyses. The "private affairs" between governing regimes and entrenched market/rent-seeking agents continue to be influential and it is more so in resource-rich countries where potential benefits are very large (with clear agency overlap between "the business of politics" and "the politics of business").

The risk (possibility) of governments interfering in company operations (Eiteman and Stonehill, 1973; Henisz and Zelner, 2010); the risk (probability) of local/socio-political events disrupting company operations (Brewer, 1981; Aliber, 1975); the risk of legally imposed (domestic or global) environmental regulations (Robock, 1971); and the risk of fundamental shift in the domestic (host-country) governing systems can all affect the political stability of a country, thus impact the cost (economic risk) of doing business in a country (Karl, 2007).

Caselli and Tesei (2016) argued that the "perceived" stability of a controlling regime could not predict the country's future stability, which is evident in what happened in many nations (some of which were/are resource-rich economies) over the past decade. Reporting on political risk stability, Feng (1997) addressed the "types" of political regimes and argued that extreme political regime changes are most detrimental to multinational companies (foreign direct investment); and that "younger" political systems are less willing to change and adopt new policies, thus becoming more prone to disruptions. Moreover, economic pressure puts political systems under stress and forces public institutions to either adapt and modernize, or be replaced.

The global level of oil production will inevitably decline (Bentley, 2002), as the world supply for most oil-producing countries is reaching (or has reached) its limits. Oil-exporting countries in the middle east region remain, arguably, the exception to that – given its available data regarding reserves and production.

The sustainability of exploration and production (E&P) in the middle east, however, requires vast investments alongside advanced field technologies. This combination, of large foreign direct investments as well as knowledge deployment and transfer, if indeed occurs, would lead to increased production on the mid-term prospect for the global markets (demand side); but faster depletion on the long-run outlook for producing and exporting countries (supply side).

Additionally, the enormous sums of the long-term investments needed would require investors (typically large MNCs) to properly evaluate the risks involved when entering new countries using their own funds; from economic and political (macro-level) risks, to operational and financial (micro-level) risks associated with accurate E&P expectations. Owen et al. (2010) pointed that the status of current global oil reserves is unclear, but could be determined if a unified and standardized description for grade, type, and method of disclosing estimated volumes is agreed. These estimated volumes can then be economically exploited.

Given the level of discrepancies in official and publicly available (unreliable) data on true (proven and recoverable) oil reserves across oil-producing countries, though, makes it improbable that those countries would be able to change and adopt new approaches to their "way of doing business;" thus will not be able to attract the "right" (and needed) type of investment. This is amplified by the fact that most of those countries do not have sufficient funds, due to their inflated budgets ("social contract" spending), to finance such projects on their own – assuming that the needed technologies are available and are for sale. This means the world could expect reducing global productions; and oil-exporting countries could face decreasing revenues (worst for single-source economies), squeezed budgets (worst for "social-contracted" systems), and socio-political unrest (worst for poor-labor countries).

For the purpose of this work and as shown in Table 4, a very-stable country, one with open and competitive markets, transparent and high-quality institutions, adoptive governments, and lawful societies (strong legal enforcement), will have an assigned risk-impact factor (γ) for the political-stability risk type of [0]. A quasi-stable country, one with at least two of the above-mentioned factors, will have an assigned risk-impact factor (γ) for the political-stability risk type of [0.5]. An unstable country, one with less than two of the aforementioned factors, will have an assigned risk-impact factor (γ) for the political-stability risk type of [1].

3.4. Hypothetical Case Study

We will simulate a case where oil reserves are to be estimated, using equation (2), and see how both risk-impact weight % (*w*) and risk-impact factor (γ) could be assigned unprejudicedly. Table 5 shows a hypothetical case for an oil field where reservoir size and petrophysical properties were estimated.

These parameters were estimated during exploration and get periodically updated throughout the production phase of oil. As shown in Table 5, three scenarios were postulated: lower-bound; middle-bound; and upper-bound scenarios. Values listed in lower-bound scenario are most conservative, while those postulated in upper bound are least conservative. Middle-bound values are expected to fall in between lower and upper bound values as seen in Figure 3.

Table 5: A hypothetical case for an oil field

Bound	Reservoir Area (ft^2)	Reservoir Height (ft)	ϕ	(S_w)	(B_o)	Reserves (STB)
Lower	26,900	65.6	0.15	0.70	1.02	6.04E+08
Middle	32,292	98.4	0.20	0.72	1.15	1.20E+09
Upper	37.674	131.2	0.25	0.75	1.18	2.03E+09

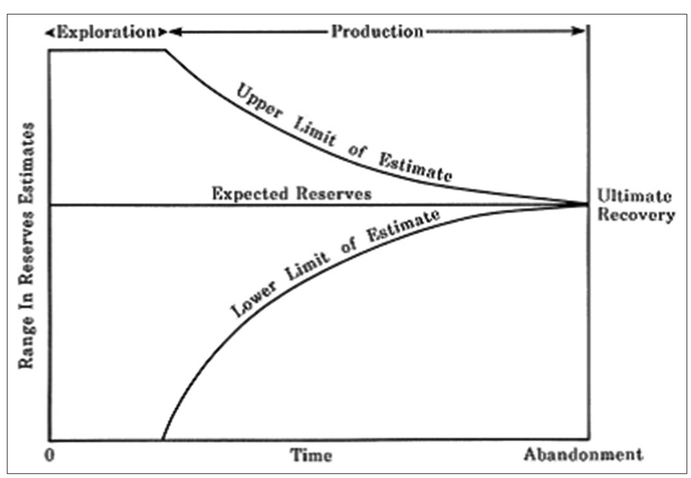
As seen from Table 5, upper-bound reserves estimate is 3.36 times higher than that of lower bound. Most oil-producing countries tend to declare upper-bound reserves values in their official announcements for economic purposes. Such unethical, irresponsible, and untransparent practice may have serious economic consequences not only on the host country but also on the whole world. False or overstated reserves data may give a false sense of security regarding global oil supply and, as a result, hinder efforts for the development and deployment of other energy resources (Esen and Oral, 2016).

Our theory proposes the assignment of a risk-impact factor (γ) based on reliability and credibility of reserves declared by producing countries. As shown in Tables 2 and 5, upper-bound reserve estimates fetch a (γ) value of [1] reflecting non-reliability of reserves estimates, while lower-bound reserves estimates are given a (γ) value of [0] suggesting plausible reserve-estimates reliability. Gauging reliability and credibility of reserves estimates is an objective task and takes into account many technical and non-technical factors such as host-country's reputation; nearby field reserves; expertise and integrity of the evaluator; history of country's fields reserves and production; technological advances; oil field labor skills; and others. At the discretion of the evaluator, risk-impact factor (γ) may take any value within the range of [0] to [1].

The assignment of risk-impact weight % (*w*) depends mainly on the country's overall economic-structure stability and revenue-sources diversity. For example, the weight of oil and gas reserves and production risk for Gulf Cooperation Council (GCC) countries is expected to be higher than that for United States of America. Generally speaking, oil and gas portfolio in diversified economies will carry less economic weight than that in single-source countries.

To illustrate the use of equations (3) and (4), we will revisit the example discussed in Table 5. We will calculate oil and gas sustainability (α) by varying the degree of oil and gas reserves-estimate reliability assuming: (1) Annual production of (1%) of total estimated reserves; (2) single-source economy; and (3) unstable-

Figure 3: Lower, middle, and upper bounds estimates as a function pf time



political regime. The lower-bound estimate is most conservative and is given a risk-impact factor (γ) of [0], reflecting credibility and reliability of reserves (conservative) estimates. The middle- and upper-bound estimates are less conservative, thus less reliable, and therefore are assigned (γ) values of [0.5] and [1] respectively.

Figure 4 shows sustainability of oil and gas reserves estimates (α) as a function of risk impact factor (γ) assuming the following risk impact weight (w) %: oil and gas reserves and production risk (60%); economy health risk (20%); political stability risk (20%). Figure 5 shows sustainability of oil and gas reserves estimates (α) as a function of risk impact weight (w) % for lower-, middle-, and upper-reserves estimates assuming 1:1 weight (w %) ratio for economy health and political stability risks.

As shown in Figure 4, it is valid to argue that the "sustainability" of oil and gas reserves (α) changes profoundly in connection with the risks associated with the process of reserves estimation. In fact, the (α) factor drops by 45.1% when reliable reserves (γ = 0) are compared with unreliable reserves (γ = 1). This proves the importance of integrity and expertise of the evaluator.

Kaufmann et al. (2008) argued that contradictions appear to exist between single oil fields data for oil producing and exporting countries (OPEC), and the publicly announced data for the same fields on aggregate. Therefore, one could argue that most, if not all, oil producing and exporting countries publicly announced reserves are not reliable and require significant re-evaluation and review by independent experts.

Unfortunately, there exists no mechanism for verifying and challenging reserve estimates declared by OPEC members. On the contrary, reserve estimates and inventory volumes announced by internationally accredited and publicly traded companies are more accurate as it is subject to constant examination and scrutiny (Behrouzifar et al., 2019).

It is shown in Figure 5 that sustainability factor (α) increases as the weight (w) % assigned to oil and gas reserves and production increases; and as the weight designated for economy health and political stability decreases. This could be seen from the rise in lower and middle-bound reserve estimates, as the risk impact weight changed from 10% to 100%.

Figure 4: Sustainability of oil and gas reserves estimates (α) as a function of risk impact factor (□)

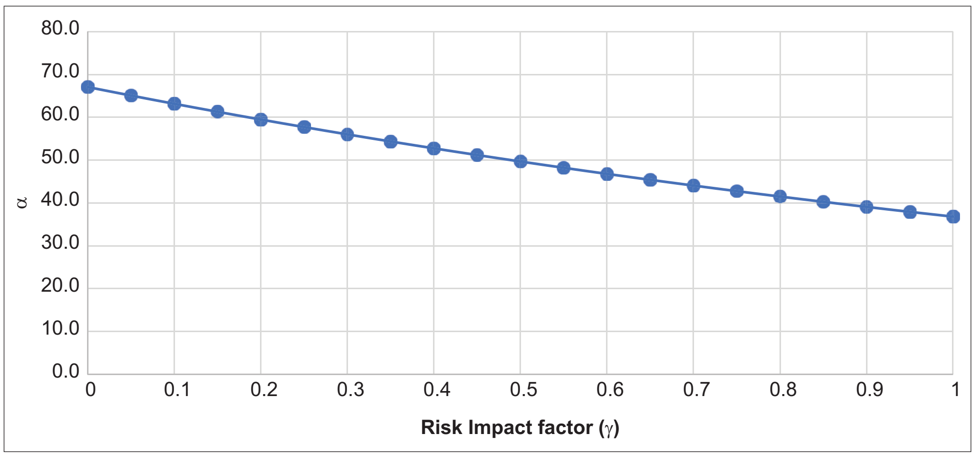
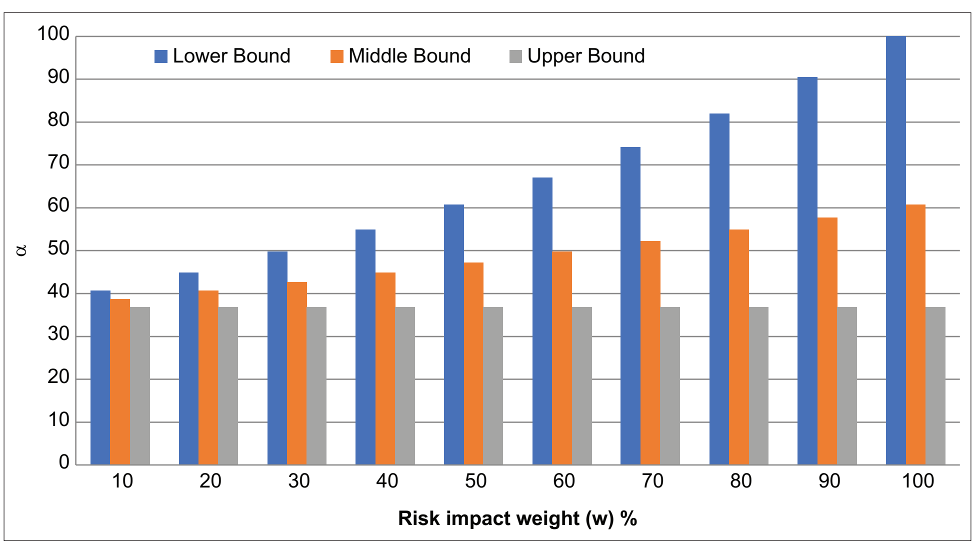


Figure 5: Sustainability of oil and gas reserves estimates (α) as a function of risk impact weight (w) % for lower, middle and upper reserves estimates



While increasing the impact weight (w) % increases the (α) factor, since more weight is given to oil and gas reserves, it also increases the risk impact factor (γ) especially if such estimates are unreliable. Therefore, increasing the weight of unreliable oil and gas reserves in the country's economic portfolio may not prove beneficial to oil and gas sustainability factor (α) due to the risks inherited in the estimation process.

It follows that purposely overestimating oil and gas reserves to gain economic advantages may lead to serious economic problems both locally and globally. In addition, ignoring economic and political factors when evaluating the overall sustainability of oil and gas may give a false sense of lifelong and security for global supply.

4. CONCLUSION

Besides reliable reserves estimates and accurate annual production data, oil and gas sustainability should take into account other factors which could have a great impact and levy a great deal of risk to the overall sustainability of oil and gas resources. Such factors include, but not limited to, health of the economy and political stability of the producing (exporting) country.

According to our newly modified formula (equation 3), oil and gas sustainability could drop by as much as 46.1% if one considers, along with technical risks associated with oil and gas reserves and production; the risks associated with economic health; and risk associated with political stability of the producing country. These types of risks, although known, are often ignored when evaluating "sustainability of oil and gas" of a certain producing country especially those located in MENA region.

The use of a (β) factor in our modified equation gives us the freedom to consider all types of risks that could affect the sustainability of oil and gas reserves. This is made possible using equation (4), where (β) factor is calculated from risk impact factor (γ) and risk impact weight % (w) for each risk type. One of the additional challenges, besides obtaining reliable oil and gas reserves and production data, is assigning numerical values to (γ) and (w) factors to reflect their respective risk levels.

This presented methodology is valid if all data associated with oil and gas reserves and production, economy status, and political stability are reliable and accurate. In addition, an expert opinion is critical when evaluating (γ) and (w) factors.

Future work will include expanding the types of risks affecting oil and gas sustainability; and incorporating them into equations (3) and (4) in order to get a better picture of oil and gas sustainability for oil producing countries.

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