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Research Article

A Prediction on Nigeria's Oil Depletion Based on Hubbert's Model and the Need for Renewable Energy

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The paper examined Nigeria's oil sector in order to get a time point of total depletion. Data for production rate, *P*, was sourced from 1958–2008 for the study. This research employed Hubbert's Model that based the peaking of oil reserves on the simulation of a bell-shaped curve that rises rapidly to a peak and declines just as quickly. MATLAB tool was employed in the analysis of data. Findings include that there is an imminent decline in Nigeria's oil reserve since peaking could have occurred or just about to occur; this is shown to be in agreement with previous studies, and an account of how oil depletion will affect domestic use of energy is also highlighted. Recommendations amongst others include the immediate adoption of Hirsch Report on the employment of mitigation efforts like alternative energy investments in order to tackle the dire effects which may come as economic, social, and political demands in the wake of a sudden decline, as well as domesticating energy retail by setting up small- and medium-scale enterprises (SMEs) which are empowered to provide basic energy source using renewable energy resources.

1. Introduction

As of January 1, 2009, proved world oil reserves, as reported by the Oil & Gas Journal, were estimated at 1,342 billion barrels—10 billion barrels (about 1 percent) higher than the estimate for 2008 as referred in [1]. This proved reserves of crude oil, according to [2], are the estimated quantities that geological and engineering data indicate can be recovered in future years from known reservoirs, assuming existing technology and current economic and operating conditions.

However, oil reserves include both *crude reserves* and *other reserves* with several reserve classification systems such as measured reserves, indicated reserves, inferred reserves, probable reserves, and possible reserves as discussed in [3]. Apparently, other reserves are generally less well known and therefore less precisely quantifiable than proved reserves, and their eventual recovery is less assured.

History is punctuated by periodic claims that oil reserves will be exhausted, followed by the discovery of new oil fields and the development of technologies for recovering additional supplies; this is outlined in [4] as follows.

(i) An 1855 advertisement from Kier's Rock Oil advising consumers to "hurry, before this wonderful product is depleted from Nature's laboratory."

(ii) The estimate in 1874 from the state geologist of Pennsylvania, US leading oil producing state, that only enough US oil remained to keep the nation's kerosene lamps burning for four years.

(iii) The 1973 Arab oil embargo which gave rise to renewed claims that the world's oil supply would be exhausted shortly.

(iv) A forecast by an expert in 1989 that world oil production would peak that very year and oil prices would reach $50 a barrel by 1994.

(v) A respected geologist in 1995 predicted in *World Oil* that petroleum production would peak in 1996 and after 1999 major increases in crude oil prices would have dire consequences.

(vi) A 1998 Scientific American article entitled "The end of cheap oil" predicted that world oil production

> would peak in 2002 and warned that "what our society does face, and soon, is the end of the abundant and cheap oil on which all industrial nations depend."

Two most influential scientific journals in the world, Nature and Science, have at some time also predicted the looming danger of dwindling oil reserves. A 1998 article in *Science* was titled "The next oil crisis looms large—and perhaps close" discussed by Kerr [5]; while a 1999 *Nature* article was subtitled "[A] permanent decline in global oil production rate is virtually certain to begin within 20 years" by Hatfield [6]. But contrary studies have adduced that the rate at which oil reserves are being utilized is less, if not equal to, than the rate at which it is being replenished as discussed in [4, 7].

In cases where the theory of dwindling oil reserves has been categorically downplayed, Hubbert's Model of Energy Production has remained a source for reemphasis. The prediction by Hubbert in 1956 that oil production from the 48 contiguous United States would peak between 1965 and 1970 was accurate. Hubbert based his estimate on a mathematical model that assumes that the production of oil resource follows a bell-shaped curve—one that rises rapidly to a peak and declines just as quickly.

According to Oil & Gas Journal (OGJ), Nigeria had 36.2 billion barrels of proven oil reserves as of January 2007, while the government plans to expand its proven reserves to 40 billion barrels by 2010. The majority of reserves are found along the country's Niger River Delta, in southern Nigeria and offshore in the Bight of Benin, Gulf of Guinea and Bight of Bonny. Nigeria has total production capacity (total potential production capacity if all oil currently shut-in came back online) of three million barrels per day (bbl/d) including two million bbl/d onshore and one million bbl/d offshore.

Currently, Nigeria is the largest oil producer in Africa, the eleventh largest producer of crude oil in the world, and has a potential of increasing oil production capacity to four million bbl/d by 2010. Nigeria is the world's eighth largest exporter of crude oil and the country is a major oil exporter to the United States. In 2006, Nigeria's total oil exports reached an estimated 2.15 million bbl/d. Nigeria shipped approximately one million bbl/d or 42 percent of its crude exports to the United States in 2006. Additional importers of Nigerian crude oil include Europe (19 percent), South America (7.6 percent), Asia, and the Caribbean.

The high rate of depletion of oil reserves worldwide is a cause for worry as well as the fact that the Nigerian economy is heavily dependent on the oil sector which, according to the World Bank, accounts for over 95 percent of export earnings and about 85 percent of government revenues. And so, this paper is intended to project on the imminence of Nigeria's dwindling oil reserves and the "unity probability" in the eventual depletion of its relative resource/reserve occurrence as well as what it holds for its oil-over dependent energy sector.

Nigeria comes as a case under study because of its current grandstanding in diversifying in emerging renewable energy—another energy form with similar abundant endowment and other viable but neglected energy sources coupled with the dire economic challenge inherent in its revenue generation. This approach is in contrast with the recent Hirsch report [8] which states "The peaking of world oil production presents the U.S. and the world with an unprecedented risk management problem. As peaking is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented. Viable mitigation options exist on both the supply and demand sides, but to have substantial impact, they must be initiated more than a decade in advance of peaking."

However certain limitations suffice in the study such as the preliminary difficulty in an unreliable database, exhibiting a wide range of estimates from different sources, with many displaying brief internal inconsistencies. The definition of the various terms in wide use is another difficulty. In particular, the term reserve has been biased commercially, financially, and politically. Again, the estimates derived in this study cannot be passed off 100% because of unpredictable tendencies for oil reserves to grow by the application of current or emerging technology on the production of available resource. The rate of decline can vary from field to field, and this affects calculations on the size of the reserves. A further factor is the expected size of future demand for oil.

In the end, it is expected that this study will add to the growing database of research into Nigeria's oil and gas sector with a priority emphasis on the inevitable danger in delaying alternative actions in prevailing over the crude mono-culture.

2. Methodology

This research employed Hubbert's Model that based the peaking of oil reserves on the simulation of a bell-shaped curve that rises rapidly to a peak and declines just as quickly. In this case, the model requires an accurate estimate of the size of Nigeria's total oil endowment. MATLAB tool simulated the compiled data and thereafter plotted simple graphs which were used to show the results of the analysis. However, due to the bulky nature of data for oil production in 1958–2008, it cannot be completely captured in this paper but the sources have been appropriately referred.

Hubbert [9] first applied his analysis to the lower 48 states of the USA (i.e., those excluding Hawaii and Alaska) in 1956 and predicted that oil production would reach a maximum (peak oil) either in 1965 or 1970, depending on his estimate of the total volume of the oil reserve there, of either 150 or 200 billion barrels, respectively. The derivation of Hubbert's analysis which is predictive [10, 11] has become known as the "Hubbert Linearization." The Hubbert Peak can be represented by the logistic differential equation

$$\frac{\delta\vartheta}{\delta\tau} = P = \alpha\vartheta\left(1 - \frac{\vartheta}{\vartheta_\tau}\right), \tag{1}$$

where P is the production (number of barrels of oil) per year, φ is the cumulative production (i.e., the total amount

of oil recovered from the source to date), ϑ_τ is the total amount of oil that will ever be recovered from it, and α is the logistic growth rate (described in [11] as a "sort of compound interest"). Equation (1) is quadratic (and describes a parabola or bell-shaped curve, see Figure 1) but may be rewritten in linear form, by dividing by φ to give (2) and then (3), which is simply the assumption that the relation P/ϑ versus ϑ plots a straight line in which η is the line's inclination:

$$\frac{P}{\vartheta} = \alpha - \frac{\alpha\vartheta}{\vartheta_\tau}, \tag{2}$$

$$\frac{P}{\vartheta} = \alpha - \eta\vartheta. \tag{3}$$

In order to determine the Hubbert Peak for Nigeria's oil reserve, two sets of data, the annual production, called P, and the cumulative production, known as ϑ in 1978–2008, were sourced and simulated. Annual production figures for Nigeria are available elsewhere in [12, 13]. The cumulative production was calculated from P (1978–2008) coupled with relevant data available for it from 1958–1978 retrieved from [13] of which 6.79 bbl represented Nigeria's cumulative oil production within this period.

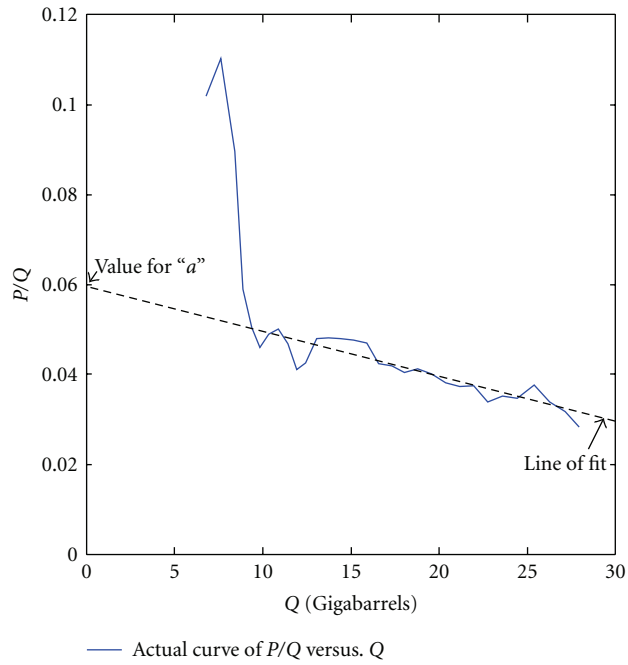

Figure 1: The plot of P/ϑ versus ϑ for Nigeria's oil production in 1978–2008.

3. Result Analysis and Discussion

With the help of MATLAB tool, the value of P/ϑ for each year was determined and a graph of P/ϑ versus ϑ was plotted to get the graph as shown in Figure 1.

The plot of P/ϑ (i.e., the number of barrels of oil produced each year divided by the total amount of oil extracted to date) versus ϑ (the total amount of oil extracted to date) directly gave a straight line when fitted (Figure 1) with a y-axis intercept equal to "α", and a slope "m", that is, $-\alpha/\vartheta_\tau$. The line fitted to these dots has a value of 0.06 for α, and $-8.695 \times 10\text{E-}13$ for η. With this straight line we can find the value of ϑ for which P/ϑ is zero, in this case 69.005 bbl (approximately 70 bbl), represented as ϑ_τ. This value is the maximum cumulative production that will ever be achieved. From the obtained values for m and ϑ_τ, values for P were estimated using (1), for each unit value of ϑ, from which it is apparent that the ability to produce oil depends entirely on the "unproduced fraction," $(1 - \vartheta/\vartheta_\tau)$, that is, how much oil there is remaining in the well and on nothing else. Similarly, the value of ϑ_τ could also be given by the intercept on the x-axis, since it corresponds to the point at which the resource is exhausted and $P/\vartheta = 0$ if the plotted straight line in Figure 1 is extended to touch the x-axis.

To make a plot of P against time, that is, a classic production curve, it was necessary to replace ϑ as the x-axis unit by time (i.e., by year). This was done by noting that $P = \delta\vartheta/\delta\tau$, as (1); hence $1/P = \delta\tau/\delta\vartheta$. By using (1), values of P can be predicted for each barrel of oil (billion barrels of oil in this case), by increasing or decreasing ϑ by increments of one (billion barrel) unit from cumulative production at a specified year (to act as a "clock," e.g., $\vartheta = 18$ billion barrels in 1998). Dividing the P values into 1, the reciprocals $(1/P)$—in units of years per billion barrels rather than of billion barrels per year (P)—were obtained. Then for each value of P, a year-fraction was calculated (i.e., how long it took to produce each billion barrel unit) a production plot of P versus year-fraction was made, giving the curve in Figure 2, the area under which is equal to the total volume of the resource, ϑ_τ.

The bell-shaped curve approximation modeled for Nigeria's oil production as a function time—a standard factor of the Hubbert's Model—in Figure 2 is such that it agrees with earlier studies discussed in [4–6, 14–22] that suggest oil production will reach a maximum—a peak—and then decline, albeit the timing could be uncertain, either occurring earlier or later. The curve depicts that the onset of the peak will occur quite suddenly after which the decline becomes very steep. The forecast, in line with BP's report [23], shows the imminence of Nigeria exhausting its proven reserves notwithstanding the fact that it has grown dramatically in the last decade. Similarly, recent IEA estimates reported by Connor [24] project that the decline in oil production in existing fields is now running at 6.7 per cent a year compared to the 3.7 per cent decline estimated in 2007, which was later acknowledged to be wrong.

To this end, the results show that dwindling oil reserves in Nigeria is a cause for worry which requires a proactive approach as it agrees with earlier forecasts as the task of managing conventional oil peaking has been identified as very challenging by Hirsch [25]. Also, Hirsch et al. [8] state that the dire effects which come as economic, social and political demands premeditate mitigation efforts supposedly initiated far ahead of the time before peaking occurs. Energy deficit, scarcity of liquid fuels, higher oil prices, and certain economic hardship are just few of such

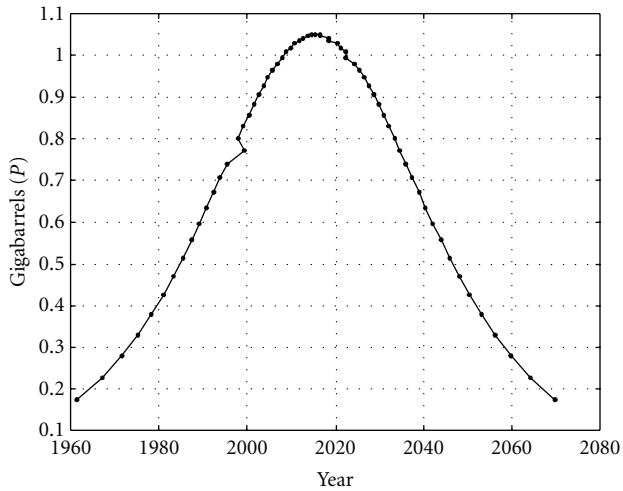

Figure 2: Hubbert's oil production curve showing Nigeria's likely oil peak.

Table 1: Nigeria's energy reserves/potentials.

Resource	Reserves	Reserves billion toe
Hydropower	10000 MW	
Hydropower	734 MW	Provisional
Fuelwood	13071464 has (forest land 1981)	Estimate
Animal waste	61 million tonnes/yr	Estimate
Crop Residue	83 million tonnes/yr	Estimate
Solar Radiation	3.5-7.0 k Wh/m 2-day	Estimate
Wind	2–4 m/s (annual average)	

Source: Renewable Energy Master Plan (2005).

adverse effects anticipated in Nigeria for instance. However, since estimations of oil peak have never been 100% accurate, it virtually raises no limitation as it gives room for options for mitigation as argued by Hirsch [26].

The mitigation efforts are expected to come in the form of energy transition, time-dependent actions, multisector involvement, capital investment, government intervention, risk management, and professional involvement. A number of technologies currently available require immediate implementation. What Nigeria requires more, though, is the need to accelerate efforts in the direction of abundant renewable energy. This is in tandem with an April 2007 KPMG survey [27] on 553 financial executives from oil and gas companies that reveals the option of government funding and private equity directed at renewable energy sources as key to addressing declining oil reserves. Currently, there is little information on the economic consequences of dwindling oil reserves in Nigeria as the process is still in phase. However, future forecasts reveal that they will be dire.

Worth mentioning too is that, since all households survive daily on basic energy requirements, they stand to suffer most in the event of a sudden oil decline because virtually all household materials and activities are oil energy dependent. Petrochemicals for instance are key components to much more than just the gas in cars as they are highly utilized in modern food production. So also are pesticides and agrochemicals which are made from oil; commercial fertilizers are made from ammonia, which is made from natural gas, which is also peaking in the near future.

Most farming implements such as tractors and trailers are constructed and powered using oil-derived fuels. Food storage systems such as refrigerators are manufactured in oil-powered plants, distributed using oil-powered transportation networks and usually run on electricity, which most often comes from natural gas or coal.

In addition to transportation, food, water, and modern medicine, mass quantities of oil are required for all plastics, all computers, and all high-tech devices. Some specific examples may help illustrate the degree to which our technological base is dependent on fossil fuels: the construction of the average desktop computer consumes ten times its weight in fossil fuels; the explosive spread of the Internet, was also a product of the era of ultra cheap energy such that the hardware of the Internet, with its worldwide connections, its vast server farms, and its billions of interlinked home and business computers, probably counts as the largest infrastructure project ever created and deployed in a two decade period in history; when considering the role of oil in the production of modern technology, it is noteworthy that most alternative systems of energy—including solar panels/solar—nanotechnology, windmills, hydrogen fuel cells, biodiesel production facilities, nuclear power plants, and so forth rely on sophisticated technology and energy-intensive forms of metallurgy.

Therefore, in the current depletion of oil reserves in Nigeria, domestic users of energy will suffer more as it will not only lead to higher procurement costs due to scarcity, but also a corresponding increase in basic cost of living leading.

4. Conclusion

This paper is simply concerned with the dwindling rate of Nigeria's oil reserve that is being taken lightly by concerned stakeholders. After the gathering of oil production per year data in 1958–2008 (50 years), Hubbert's Model was necessary for analysis using MATLAB tool. The results show that an initial rise in Nigeria's oil reserve value grows steadily to a peak and quickly comes back to zero, forming a bell shaped-curve. This paper therefore becomes necessary to establish the reality of a projected but certain fall of Nigeria's oil reserve as confirmed in relevant studies. This will eventually boil down to additional crises in power and revenue generation and among other sectors since there is overdependence on liquid fuel for power generation and government revenue in Nigeria which will translate in to more burden for domestic energy use. Certain limitations which existed during the study were

earlier identified as unreliable database as a result of social, political, and economic bias.

5. Recommendations

In the near future, opportunities for further research can be explored in terms of the way mitigation efforts can be harnessed and collaborated in order to produce both immediate and sustainable results. A prevailing large-scale example is the DESERTEC Solar Project. DESERTEC is a consortium of a dozen or so European companies which calls for tapping the North African desert's sweltering sun to produce enough carbon-free solar electric power to satisfy 15% of Europe's electrical demand in 2050. If actions to implement are speedily developed, Nigeria can pose a big encouragement to other African countries by harnessing its enormous untapped reservoir of renewable energy resources that includes, other than solar power, biomass and wind by exploring SME options to tackle remote energy demand. There are proven locations of great renewable energy potentials in Nigeria. Table 1 shows various renewable energy sources and their estimated reserves in Nigeria.

In very clear terms, the bleak future of the looming dwindling oil reserves can also be renewed via an increased investment and utilization of renewable energy resources and systems in Nigeria and elsewhere. Moreover, with the dependency of all other sources of energy on oil, it will be reasonable if such energy transition is speedily initiated so as to avert a situation whereby the economic fallout from high prices will almost certainly cause geopolitical tensions (i.e., war) thereby further hampering the development of large-scale alternative sources of energy. This is where the socioeconomic and political benefits in deploying renewable energy to replace the declining conventional energy sources can be appraised. Economically, this option can successfully be domesticated in every household by setting up SMEs which are empowered to provide basic energy source using renewable energy resources by optimising procurement costs and providing jobs. Socially, there will be no need to fight over pollution and resource control as renewable energy is environmental friendly and geographically unbounded. Politically, countries may not need to go to war again on the grounds of oil exploration or land border definitions.

The potentials and development vista for Nigeria in deploying large-scale renewable energy have been systematically discussed in the Renewable Energy Master Plan (REMP) [28] and a review undertaken and available for information and accelerated action in an earlier work by the authors [29]. The example of Germany and Brazil where public support and taxed oil drove success in alternative energy adoption is also a challenge to the present cause.

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