Review Article

Marginal Fields Development in Nigeria: A Review of Extant Strategies

Abstract

This paper focuses on the development of marginal fields in Nigeria, the challenges, economic viability, and the role of the government in implementing the contributions of marginal fields to the national oil production output. Also, the previously reported marginal field development and management practices in the Niger Delta oilfield are x-rayed. Following the definition of the marginal field, an overview of different types of marginal field development in the Niger Delta. Also, the United Kingdom Oil and Gas Recovery Regulatory Commission, the United States Security Exchange Commission, and the Nigerian government's categorization of what compose of a marginal field are included. In addition, the participation of the Nigerian federal government and contributions to the development of marginal fields in the bidding of marginal assets to the development of infrastructure are presented. Particular attention is paid to the factors that affect the development and choice of production strategies in the marginal fields of the Niger Delta. These factors discussed in detail in the document include environmental, technical, social, political, and economic factors. Again, different management and development strategies used by some marginal fields of the Niger Delta are x-rayed and presented with a particular focus on three of those strategies. The three common approaches in the Niger Delta marginal field development strategy are water flooding, infill drilling, and infrastructure sharing. These approaches have made marginal fields in Nigeria operational, competitive, and economically viable to date.

Keywords: Marginal fields, Development strategies, Production plan, Niger Delta region

1 Introduction

International oil and gas companies can abandon oil and gas reserves for economic, technical, or strategic considerations. Reserves, or more appropriately, resources abandoned in this manner, are termed “Marginal” resources (Dagogo *et al.,* 2008). They are smaller oil and gas fields that are typically under-used due to their insufficient reserves (Idachaba and Wokoma, 2017), a lack of local infrastructure, prohibitive development costs, a lack of sufficient net income to justify development at a given time, environmental concerns, political stability, accessibility, and remoteness (Akpanika and Udoh, 2008).

According to the United Kingdom (UK), oil and gas recovery regulatory commission, marginal fields can be broadly categorized as having any of the following five characteristics (Chidozie and James, 2014):

i. low recoverable reserves as a result of the low initial storage tank oil in place (STOIIP).

ii. the field is too far from the existing production facilities to be economically viable to develop and bring on stream.
iii. fields not yet considered for development due to marginal economics considering the prevailing economic and financial climate.
iv. fields that are technically difficult to develop or cannot be produced using conventional methods.
v. Low volume producing fields that have lost their economic viability because the production income is less than operating expenses.

These classifications according to UK oil and gas experts became important in reversing the alarming trends prevalent in the UK oil and gas industry as few new reserves are discovered on the continental shelf of the UK (Ian, 2014). Those worrisome observations include declining production, increasing production, ageing assets, and diminishing exploration drilling (James, 2011).

According to the definitions of the Nigerian government, marginal oil fields are those that (Toluse *et al*., 2016; Akinduyite *et al.*, 2022):

vi. have technological, economic, and geological limitations.
vii. lack of nearby production facilities to start up.
viii. are in an unfavorable financial and market situation.
ix. are unfavorable or poor crude characteristics, e.g., a high crude viscosity.
x. the Multinational Oil Company (MOC) left underdeveloped for about ten years with only a few or one well.
xi. The MOC may not be economically feasible to develop because of its low reserve.
xii. That might not be able to produce 10,000 barrels of oil per day.

The last three criteria used in the Nigerian classification of marginal resources are peculiar to the Nigerian system of operation and may not apply outside the system. The phrase "marginal oil resource" refers to oil formations that have been identified as resources (Pan *et al., 2022)* but do not quite fit the bill to be considered reserves or economic reserves (Encyclopedia, 2023). Although the use of enhanced oil recovery (EOR) or hydraulic fracturing can lead to an economic commercial oil flow criterion (SPE, 2020), this kind of resource still does not meet the definition and standard of the U.S. Securities and Exchange Commission (SEC) (SEC, 2006). This is because effective reserve and economic evaluations cannot be done in accordance with the SEC reserve evaluation standards.

By the SEC definition, oil reserves are those that are 'judged to be economically producible in future years from known reservoirs under existing economic and operating conditions and assuming the continuation of current regulatory practices using conventional production methods and equipment' (SEC, 2006). Petroleum reserves are classified as proved, proved developed, proved undeveloped, probable, or possible reserves according to these SEC standards (Szatkowski, 2008). However, marginal resources are not included in these reserve classifications because a marginal resource reservoir does not fit within the effective thickness specified in these standards. The classification of a marginal resource as a resource rather than a reserve is largely due to the thinness of its reservoir formation (Encyclopedia, 2023). It goes without saying that several amounts of marginal resources have neither been explicitly stated in any oilfield development plans (Maheshwari *et al*., 2020) nor formally included in the world's

reserve statistics to date because the foundation for their total reserves calculations has not been fully established (Livernois, 2000).

Both marginal Type I and marginal Type II resources fall into this category of resources. The definition of a Marginal I resource is a resource formation identified as sandstone for which the effective thickness standard of 0.2 m cannot be met (Encyclopedia, 2023). This kind of marginal resource has been perforated and developed, but its development is less efficient compared to a productive viable pay zone (Liu, 2020). Compared to poor reserves, the average permeability, porosity, and initial oil saturation (So) are 180 mD, 25%, and 45 %, respectively. A resource formation that is not acknowledged as a sandstone formation is referred to as a Marginal II resource. Its permeability, porosity, and oil saturation are 60 md, 20%, and 35% lower than those of Marginal Type I, respectively, indicating lower reservoir quality (Pan *et al.*, 2022).

According to Pan *et al*. (2022), taking into account physical attributes and contact relationships with other reserve layers, marginal resources can be further divided into two basic types.

i. *Isolated marginal resources consist of a single layer that is only made up of a marginal resource, with a separation layer from a reserve layer that is greater than 0.5 m. They can be classified as isolated Marginal Type I resources or isolated Marginal Type II resources according to the various types of marginal reservoirs. It is possible to classify a marginal resource as isolated if it has a sandstone thickness but falls short of the effective thickness criterion.*
ii. *Connected marginal resources are marginal formations that can be found at the top or bottom of a reserve layer. They can be classified as Marginal Type I connected resources or Marginal Type II connected resources depending on whether a junction boundary is in contact with the reserve layer or if there is a separation layer and its thickness is less than 0.4 m. Their reservoir quality is very similar to isolated and connected marginal resources of type I or type II. They have no impact on the quality of their own reservoir as a result of contact relationships with other reserve layers.*

The development of marginal oil resources is typically characterized by mature oilfields saddled with uncertain economics, high operational risks, and uncertain profitability (Otombosoba and Dosunmu, 2018). Acheampong (2021) suggested using the real option method to value marginal resources in the UK while considering various uncertainties. As in the major oil-consuming regions where energy security is a major concern, the discovery, development, and management of marginal field reserves are considered a hot topic (Acheampong, 2021). Therefore, this article covers the ownership, bidding, and allocation of prevalent factors affecting, the economic assessment approach popularly used by assessors, and the development strategies involved in the development of marginal fields in Nigeria, among others. The article concludes with some examples of marginal fields developed in the Niger Delta oil field in Nigeria.

2 Nigeria Marginal Field Ownership

The conversation surrounding indigenization in the late 1990s brought the development of marginal oil fields in Nigeria to the fore. To consolidate on the gains of Nigerian government's indigenization policy in the upstream oil and gas industry and develop local content, the marginal fields award initiative was created and went into effect around 1999 (Temitope, 2017). The

initiative also aimed to create more jobs and encourage greater capital inflow into the sector (Dolo and Odendaal, 2018). It is also aimed at increasing the nation's proven and recoverable reserves (Gborogbosi, 2020). Currently, the federal government envisions increasing Nigeria's daily production rate to 3 or 4 million barrels and the reserve to 40 billion barrels (NUPRC, 2022). Both the federal government and indigenous investors believe that government acquisition of fields that large oil companies left undeveloped or abandoned for ten years and redistributing the same to intending investors would cause an increase in recoverable reserve (Offiong, 2008). Because of this, marginal field operators, mostly indigenous oil and gas companies, were given fields to develop, but many of these operators are having trouble doing so (Adetoba, 2012).

However, according to Section 44(3) of the 1999 Constitution of the Federal Republic of Nigeria, the Federal Government is granted ownership and control of all minerals, mineral oil, and natural gas on, under or on any land in Nigeria, as well as its territorial waters and exclusive economic zone (NigerianGovernment, 2004). The management of these minerals must follow any guidelines established by the National Assembly, according to the Federal Government. The licencing of oil blocks in the nation is managed by the Department of Petroleum Resources (DPR) of the Ministry of Petroleum Resources (Otombosoba and Dosunmu, 2018). The primary law regulating petroleum activities in Nigeria is the Petroleum Act of 1969. It offers comprehensive provisions for the industry's transportation, production, and exploration activities. The Federal Government of Nigeria is granted ownership of petroleum resources by the Act and the constitution, respectively (NRGI, 2010). Numerous other laws, such as the Petroleum Amendment Act of 1996 and related subsidiary laws, deal with peculiar operations of the industry. The Act's Section 2 gives the Minister for Petroleum Resources the authority to assign licences and specifies general standards for doing so (Akinduyite *et al.*, 2022; Otombosoba and Dosunmu, 2018). DPR publishes guidelines for the licencing process, prequalification requirements, required documentation, application fees, deadlines for bid document submission, and weighting criteria for technical and commercial evaluation criteria (DPR, Guidelines and Requirements for the Application of Oil and Gas Industry Service, 2017).

The Petroleum Act permits the issuance of three different types of licences that allow an organization or an entity to conduct business in the upstream portion of the oil and gas industry: an oil mining lease (OML), an oil prospecting licence (OPL), and an oil exploration licence (OEL). Since all OELs were changed to OPLs in the 1970s, only the OPL and OML are currently tenable (DPR, 2000). The Petroleum Amendment Act of 1996, in particular paragraph 16A of the amended Petroleum Act, provides for marginal fields in Nigeria as follows (Emole, 1997; Tokunbo, 2014):

> *16A. (1) The holder of an oil mining lease may, with the consent of and on such terms and conditions as may be approved by the President, farm out any marginal field which lies within the leased area.*
>
> *(2) The President may cause the farmout of a marginal field if the marginal field has been left unattended for a period of not less than 10 years from the date of the first discovery of the marginal field.*
>
> *(3) The President shall not give his consent to a farm-out or cause the farm-out of a marginal field unless he is satisfied -*

(a) that it is in the public interest to do so, and, in addition, in the case of a nonproducing field, that the marginal field has been left unattended for an unreasonable time, not being less than 10 years; and

(b) That the parties to the farm-out are in all respects acceptable to the Federal Government.

(4) For the purpose of this paragraph:

"Farm-out" means an agreement between the holder of an oil mining lease and a third party which permits the third party to explore, prospect, win, work, and carry away any petroleum encountered in a specified area during the validity of the leases; "Marginal field means such field as the President may, from time to time, identify as a marginal field."

The Petroleum Industry Act has modified the scope and changed the definition of a marginal field in Nigeria. Akinduyite *et al.* (2022) stated that:

> The marginal *field is now defined as a field or discharge that has been declared a marginal field prior to January 1, 2021 or that has been lying fallow without activity for seven years after its discovery prior to the commencement of the petroleum inductry Act.*

On the basis of the Act, there will be no new marginal fields to be declared. All marginal fields declared before January 1, 2021, that are not developed and producing shall be converted to a petroleum producing licence (PPL). In addition, operators of marginal fields that have been developed and are producing will continue with the original licence rate and farm-out agreements with the condition that the current oil mining lease (OML) will be converted to the petroleum mining lease (PML) within 18 months from the start of the petroleum industry act (Akinduyite *et al.*, 2022).

2.1 Nigeria Marginal Field Bidding and Award

Periodically, the DPR on the directions of the Minister of Petroleum allocates a marginal field to different indigenous companies after an approved process has been carried out (DPR, 2000; Tokunbo, 2014). The overall programme will begin with formal announcements of the fields available for round, as well as the guidelines on the process, stages, and application requirements which will facilitate the process from start to finish. The fields to be allocated will be announced and companies will be invited to submit proposals in tandem with the guidelines provided by the DPR. These indigenous companies must be duly registered to carry out petroleum exploration and production operations in Nigeria (DPR. 2020). A marginal field bidding round will subsequently take place to consider the companies to which the marginal fields will be allotted. A successful bidder in the marginal field bidding round will conduct a farm-out agreement with an OML holder, which allocates responsibilities and liabilities as between the area holders, as well as the royalty payable and terms for accessing infrastructure (Gborogbosi, 2020).

A farm-out agreement means an agreement between the holder of an oil mining lease and a third party that allows the third party to explore, prospect, win, work and carry away any petroleum encountered in a specified area during the validity of the leases. In this scenario, the holder of OML is only entitled to negotiation as the relationship between the two parties is likened to that of parties of a sublease, the holder of OML being the 'farmer' and the marginal field holder, the 'farmee' (Akinduyite *et al.*, 2022; DPR 2000). On 1 June 2020, the DPR on behalf of the Federal

Government announced that a total of 57 fields will be offered on land, swamp, and shallow offshore terrains. The exercise would be conducted electronically and would include expression of interest/registration; prequalification, technical and commercial bid submission, and bid evaluation. The first bid round that was formally organized by the FGN began in 2001 and was concluded in 2003. The fields covered are as shown in Figure 1. At the end of the bid round, 24 licences were awarded to 31 indigenous companies. Another bid round was proposed in 2013 with a lot of preparation and published guidelines. Unfortunately, it never held (Tokunbo, 2014: DPR., 2020).

Figure 1: Marginal Fields for the 2003 Biding Round (MBing, 2017)**.**

Another of 57 marginal fields that stretched across lands, swamps, and offshore (Figure 2) was awarded to local Nigerian investors. More than half of the awardees had accepted the offer and paid the required signature bonuses at the end of May 2021 (Marketforces, 2021: Yekin., 2022). The Federal Government's primary aim is to promote marginal field operations to grow production capacity and to increase the country's oil and gas reserves (Offiong, 2008). The new marginal fields awarded are expected to increase the Nigerian production capacity by approximately 58 MBPD and 87MMSCFPD (Aduloju, 2023). However, only effective due diligence and increased transparency in the award of marginal fields and farm-out agreements show that it can be achieved with the objective of increasing production (Otombosoba and Dosunmu, 2018). It is important to note that under the Petroleum Industry Act, the administration of marginal fields which was originally under the DPR has shifted to the Nigerian Upstream Petroleum Regulatory Commission (NUPRC). The federal government can enforce generic application regulatory practices through the commission (Gborogbosi, 2020). Furthermore, the commission reserves the power to conduct bid rounds and voluntarily farm-out marginal fields in Nigeria (Akinduyite *et al.,* 2022).

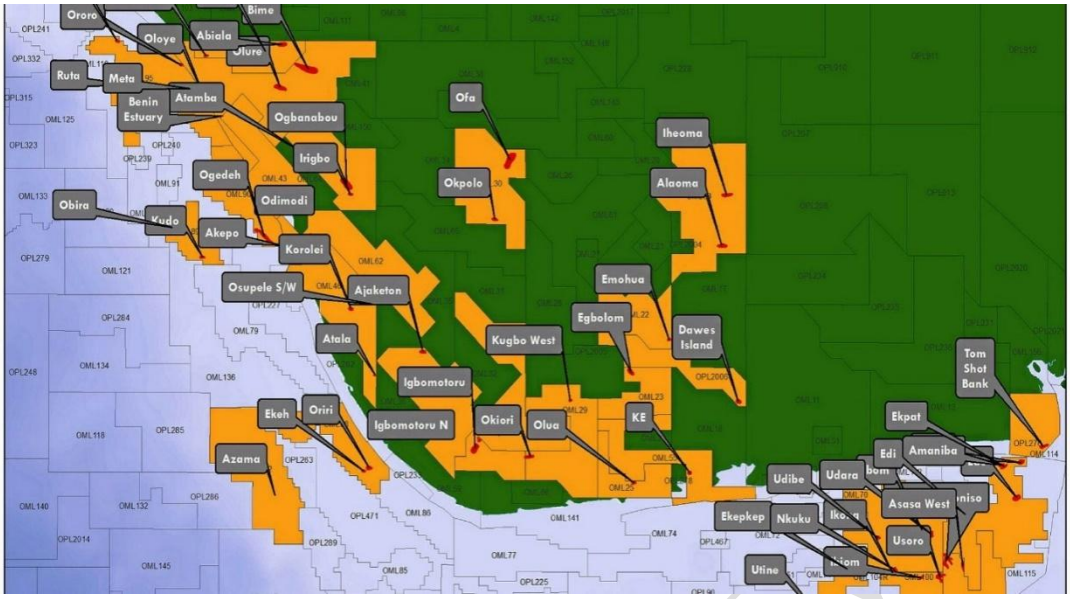

Figure 2: Marginal Fields for the 2020 Biding Round (Esau and Morgan, 2020).

3 Factors Affecting Nigeria Marginal Field Development

Otombosoba (2018) investigated exogenous factors that influence the exploitation of marginal resources in developing nations such as China, Nigeria, India, Indonesia, Malaysia and Venezuela. He discovered that the principle of sustainability, along with consideration of political, social, economic, legal, and technological issues, is essential for the successful development of marginal resources. The successful development of marginal oil fields in Nigeria has been hampered by a number of challenges (Offiong, 2008) including economic (inadequate funding/financing, inefficient or related industry), social (insecurity and risks posed by host communities), political (multiple taxes and ineffective regulation), technical (marginality of the field, technology problem and capacity building), and ecological/environmental factors (inadequate pricing of natural gas, gas flaring, etc.) (Otombosoba and Dosunmu, 2018).

3.1 Economic factors

Two economic factors that affect the development of marginal fields in Nigeria above all else are the issues of funding and supporting industries for marginal resources. These two shall be discussed in detail.

3.1.1 Funding Problem

The development of marginal fields faces a significant funding issue (Humphrey and Dosunmu, 2017; Eyankware and Esaenwi, 2019). The amount of investment in marginal field development necessary exceeds the level of government funding, which is typically in the $50-100 million range (Offia, 2011; Wood, 2012). Most marginal resources successful bidders lack the necessary funds to carry out the work schedule, so they frequently team up with other businesses or partners to raise the necessary funds. While the former aversion of the Nigerian banking system toward long-term project finance in the oil and gas upstream subsector was a notable barrier to financing, beneath the funding challenge lies the bankability of the assets, given a host of ‘soft points’ such as the inaccuracy of reserve data that burdens the economics of the fields.

(Abegunde, 2013). According to Osten (2012), Green Energy Ltd., was given Otakikpo, and All Grace Energy Ltd., was given Ubima, in 2010 because the businesses agreed to use the Public Private Partnership mechanism to finance three marginal fields pilot projects. However, for the Umusadege field joint venture partners to receive the field, they had to sign a Finance and Production Sharing Agreement (FPSA) in 2006 (Stonecap., 2012). According to the agreement, Mart Resources INC. would contribute to field development by providing 100% funding, operational support, and technical assistance. Mart would also receive a 95% share of the proceeds from the sale of the oil the field produced after all tax deductions. The performance of the first round of awarded marginal fields were largely due to foisted partnerships that resulted in several litigations instead of development (Oruwari H. O., 2020).

3.1.2 Ineffective, Related, or Support Industries

Poor infrastructure, including roads, railways, refineries, petrochemical industries, oil and gas depots, and power supply, also limits the ability of marginal field operators to develop their fields effectively and quickly. To ensure effective advancements in the fields, each of the identified poor infrastructure needs to be improved (Akinduyite *et al*., 2022). For example, investing in a refinery that would process crude if a pipeline rupture presented a transportation challenge for oil export or had to be shut down due to security concerns given the ongoing threat to marginal field operations, particularly in the Niger Delta (Otombosoba and Dosunmu, 2018). The Humphrey and Dosunmu work concluded that the development of supportive infrastructure, such as refineries and power, as well as the integration of stakeholders for collaboration is essential to sustainably develop marginal oil fields in Nigeria (Humphrey and Dosunmu, 2017).

3.2 Social Factors

Three social factors that affect the development of marginal fields in Nigeria discussed in this document are: security concerns, poor project management, and lack of participation of stakeholders.

3.2.1 Security Issues

According to the 2013 Africa oil and gas report, security problems still exist and oil theft is currently on the rise. Every day, pipelines are cut and destroyed, forcing companies to declare forced majeure about their commitments to supply crude oil (Eyankware and Esaenwi, 2019; Ogunsola-Saliu *et al.*, 2019). The situation is even worse for marginal field operators who have facilities near swamps and creeks in the Niger Delta basin, an area rife with illegal refineries (Oxford, 2022). The main issues oil companies operating onshore in the Niger Delta must deal with are the actions of militants who attack oil and gas facilities and kidnap foreign oil workers (Ogunsola-Saliu *et al.*, 2019) to draw attention to their various grievances from the international community or to obtain monetary compensation from oil companies. Indications of a bad relationship between communities and oil companies in the Niger Delta region include staff harassment, hostage-taking, vessel seizure, equipment destruction, barricades, sabotage, kidnapping, pipeline vandalism, and other incidents (Editorial., 2022). The editorial further stated that the arrest of the security situation in the Niger Delta region will result in an increase of more than 108 MBPD of oil in the national daily production capacity. A quantity that is currently lost due to theft and vandalism and affects marginal field operators.

3.2.2 Poor project management abilities

Project management is the continuous process of organizing, planning, monitoring, and controlling all aspects of a project to achieve predetermined goals. Marginal field projects should be made SMART from the beginning. The SMART acronym stands for Specific in scope, Measurable, Attainable, Relevant, and Time bound. The lack of SMART project management skills causes most marginal field projects to be delayed (Otombosoba *et al*., 2017). The Ogbelle Joint Venture's (and PETRE/NDEP's) modular project evaluation strategy and the adoption of a phased approach to developing mature projects are created to reduce controllable risk. As a result of the size of the hydrocarbon in the marginal fields, a suitable exploitation strategy must be implemented. According to Chika Chika (2013), Energia upgraded its current flow station and oil storage tanks considering the increasing production capacity to ensure that the marginal field's production could continue in the future. In 2003, the company received an abandoned well; using rigless workover operations, they were able to bring it back to life. Through effective project management and integration of all engineering, geological, and socioeconomic activities, the company successfully reprocessed and reevaluated its seismic data and drilled three additional development wells in the Ebendo field.

3.2.3 Insufficient Stakeholder's Engagement

Sufficient stakeholder participation is necessary for the marginal field development initiative to succeed in the long term. This is because public understanding and adoption of the programme are key. During a project, there is insufficient coordination and lack of communication due to dispersed decision-making at various levels. The fragmentation of interests between parties like host communities and marginal field developers, as well as the operators' limited understanding of local issues, further diminish the likelihood of a project's success. Through open dialogue between various stakeholders, the development of local stakeholders' capacities, and cooperation motivated by a common goal, these conditions can be mitigated (THISDAY, 2021). According to Toyin (2009), some international endeavors have failed due to delays and have left Nigeria. A community crisis forced Vit Oil to abandon its partnership with Goland Petroleum in the Oriri field after significant delays. In the Esit-Eket Local Government Area of Akwa Ibom State, the operations of some marginal field operators, like Frontier Oil, were in jeopardy due to the non-implementation of a Memorandum of Understanding (MoU) (BusinessDay, 2013).

3.3 Political Factors

The political factors that affect the development of marginal fields in Nigeria can vary from administration to administration. Two have been identified as persistent regardless of the administration in place. The two that will be discussed further are complex regulatory framework and tax regime.

3.3.1 Complex Regulatory Framework

The complex regulatory environment (permitting requirements, laws, and enforcement) that control the planning and permitting of oil and gas projects is built of interdependent conditions that create bottlenecks in projects (Eyankware and Esaenwi, 2019). Project delays brought on by the approval process, obtaining permits on state-owned property, and receiving approval from regulatory bodies like the Department of Petroleum Resources (DPR) (Akinduyite *et al.,* 2022)

and Federal Environment Protection Agency (FEPA), for instance, are a few examples. The challenge of navigating this complex regulatory process frequently causes projects to be delayed or even put on hold for marginal field developers with limited financial resources. According to Deloitte (2014), the start and completion of projects are frequently delayed by the approval processes for field development, which typically take 2 to 3 years. Investor relations issues arise because oil companies would have to control investor expectations while the approval process is delayed.

3.3.2 Tax Regime

Increased taxation by the local, state, and federal governments has made it difficult for some Nigerian marginal field operators to start developing their asset (Akinduyite *et al.*, 2022). Other factors affecting business operations include high operating costs and the rate of inflation. According to Fatona (2013), numerous taxes have made marginal development in Nigeria difficult to do business in and are a problem for the smooth operation of marginal fields, as this adds to the high cost of doing business in Nigeria. According to the BusinessDay (2013) report, the cost of production for local oil company operators is affecting their capacity to operate at peak efficiency. Nigerian production costs are 40% more expensive than those in other producing nations. For indigenous marginal field operators, this poses a significant obstacle. However, the petroleum industry act has reduced the marginal field operator tax rate for the maximum of marginal fields from 85% to 45%. This reduction could be seen as an incentive to encourage marginal field operators, thereby reducing the burden of marginal resource development to gear toward profitability (Afuye and Awodimila, 2022).

3.4 Technological Factors

Closely tied to the fiscal process of field awards is the adverse selection of technical and foreign equity partners, leading to inconsistency in field development and production, given fluctuating service level agreements and lopsided cost and earnings sharing negotiations. Although agriculture has been a traditional source of equity funding for marginal fields, it leaves indigenous firms at the mercy of foreign equity and technical partners, with less interest in marginal fields, an unbalanced alignment of interest, which slows field development (Eyankware and Esaenwi, 2019). More importantly, the lack of financial and project advisers in marginal fields has undermined the investment case for accessing funding, especially as project economics is often fraught with complexities and inconsistencies surrounding taxation, pricing, capital expenditure, and funding terms (UBA 2000; Akinduyite *et al.*, 2022).

3.4.1 Inadequate Technical Data

Inadequate technical data and IOC support could obstruct crude handling and processing. According to Toyin (2009), IOC refusal to provide marginal field operators with sufficient technical data has an adverse effect on the development of those fields because those operators lack easy access to seismic, petrophysical, and production data on the fields that IOCs have contracted out to them. Oyakhire and Omeke, in their study, understand the importance of accurate data in field development, especially when it comes to marginal resources. Therefore, they identified credible potential and practical solutions to overcome the data gaps often experienced during the development of marginal fields (Oyakhire and Omeke, 2017).

3.4.2 Insufficient Development of Human Capital Development

Management alone determines whether an enterprise succeeds or fails. The development of these fields suffers as a result of some licence holders for marginal fields having inadequate industry experience in oil and gas management before diving into marginal field bidding and allocation (THISDAY, 2021). The experience gap forced many marginal field operators to resort to trial-and-error restructuring (Roseline and Collins, 2017). Inadequate human capacity development could result in incorrect interpretation of reservoir or well data, which could have an avalanche effect on the overall marginal field development project (Ambastha, 2016). However, the recent steep trend in local capacity development, engineered by a new generation of indigenous talent with a good match of entrepreneurial and technical skills, should be positive for the increased contribution of marginal fields to the overall oil and gas production in Nigeria (UBA., 2020).

3.4.3 Inadequate Processing and Storage Facilities

This issue is a basic, but often overlooked, precaution when building oil and gas depots. This could serve as a price stabilization strategy during an oil glut by preventing waste and keeping excess for later use. Unsuccessful field development planning is a significant barrier that marginal operators must overcome. Ogunsola-Saliu *et al.* (2019) identified the lack of infrastructure near the vicinities of marginal fields as one of the reasons why marginal fields are left unexploited for a long time. The building of new infrastructure for oil and gas processing is considered a huge capital project, and the identified marginal reserve may not be able to cover the cost. Operators would be reluctant to expend large amounts of capital on unprofitable uncertain assets. Marginal field operators are encouraged to collaborate and share facilities where necessary for optimal utilisation of the collection, processing, transport, and exporting of oil and gas produce (Gborogbosi, 2020). This will ultimately lead to a reduced cost per barrel and improved profitability.

4 Economics of Marginal Field Development in Nigeria

The two main obstacles to developing marginal resources in Nigeria were outlined by Adetoba in his work, The *Nigerian marginal field initiative: Recent developments*". Money and lack of technological expertise appear to be the two main issues (Adetoba, 2012). Evidently, any decision about the marginal field development project is directly influenced by the economic analysis and the projected outcome. Accurately quantifying risks and uncertainty is a crucial component of any field development planning exercise, especially when information is scarce. Since the economic viability of the project depends on reducing the risk of the oil field, an accurate assessment of the downside of the project is even more important for marginal fields. Different development options carry a significant probability of negative net present value (Ogunsola-Saliu *et al.,* 2019). As a result, it is crucial to conduct a thorough and in-depth risk analysis in order to pinpoint the main causes of uncertainty in field developments and assess their overall impact on field economics. Making wise development decisions will be much easier if risks and uncertainties are better understood. These will subsequently help reduce uncertainty and move to the right or narrow the distribution of recovery and net present value. Because there are so many possible combinations in development options, evaluating and quantifying the impact of key risk factors can sometimes be a challenging process.

In general, quantitative risk and uncertainty are crucial factors in making investment decisions for the development of oil fields and in the regulation of any industrial development. Only insofar as it offers the chance of altering a choice that would otherwise have been made, does uncertainty quantification offer value. Decision making is greatly aided by the quantification of risks and uncertainties. The decision-making process in the oil and gas industry currently employs a variety of techniques. They techniques include the Worst Case/Best Case Scenario, Tornado Plots, Boston Grid, Expected Net Present Value (Team, 2023; Chang, 2023), Decision Trees, Monte Carlo Simulation, and Real Options (Ogunsola-Saliu *et al.*, 2019), to name a few. These techniques are distinguished by various levels of complexity and particular theoretical presumptions. This review study, for all intents and purposes, is limited to the application of expected net present value for the economic analysis of Nigerian marginal fields due to its budget control of uncertainties.

4.1 Expected Net Present Value (NPV)

NPV is the difference between the present value of cash inflows and outflows over a certain period (Chang, 2023). To determine the viability of a contractual agreement for a proposed marginal oil field in Nigeria, Ayodele and Frimpong (2005) performed a thorough economic analysis. The project profitability analysis, project sensitivity analysis, risk modelling, and cash flow modelling were all part of the economic analysis. The findings indicated that it is wise to invest in the expansion of Nigeria's marginal oil fields. Additionally, the outcome demonstrated that the proposed agreement results in a positive return on investment (ROI) for all parties involved. According to the sensitivity analysis of the project, the project would become unprofitable if the total cost of the seismic survey and the signature bonus increased by more than 10%. Because the discounted payback period will be longer than the anticipated project life if the price of oil falls below US$18.07, the projects must be re-evaluated. According to the risk analysis, as the NPV increases, so does the risk level attach to such an NPV.

The economics of Marginal Field Development was investigated by Akinpelu and Omole in 2009, to determine the most important factors affecting the economy. The fiscal and regulatory terms of the NNPC for 2002 were used. Because production typically dominates Nigerian Oil and Economic models, the production variable was treated as one of the main uncertain variables in the probabilistic model. According to the report, economics plays an important role in why many marginal fields do not advance past the planning stage during the budget allocation process. The results indicated that the economics of marginal fields are significantly influenced by the field decline rate, initial well productivities, and exploration and development well costs. They suggested that future research should not restrict the variables to those that affect production and well costs. The cost management strategy should take into account additional expenses, such as investments in flow lines and jackets, barge costs, and operating expenses (Akinpelu and Omole, 2009).

Adamu *et al.* (2013) provided insight on resource development, investment, and diversification in Nigeria's offshore marginal field. To perform an economic analysis for project profitability, cash flow modelling and sensitivity analysis, some parameters were used. In addition to Net Present Value (NPV), Internal Rate of Return (IRR), Present Value Rate (PVR), Payback Period and Profit-to-Investment Ratio (PIR), economic parameters are also used. Probabilistically, it was possible to be sure that the investment would have a positive NPV and good IRR values that were significantly higher than the required rate for Nigeria. According to the sensitivity analysis,

the key sensitive parameters in maximizing profit are the price of oil and the tax rate. The outcome also suggested that it would be profitable to develop marginal offshore fields in the Niger Delta of Nigeria.

Ezemonye and Clement (2013) provided information on risks that were already present using relevant available data between 2010 and 2012 to discuss the implications and validated the economic significance and implications of marginal fields in Nigeria. Using principal component analysis (PCA), a survey methodology was used. 53 risk factors were found. The PCA was successful in reducing the data to 12 risk groups suitable for Nigeria's marginal fields, including: Kernel of risk concentration, made up of 13 variables (e.g. operating costs of marginal fields, financial and economic constraints, size of the oilfield, etc.), risks related to socioeconomic and technological politics (e.g. interest rates, operational risks, exchange rates), reservoir uncertainty risks (e.g. reserves' marginality), the volume of the reservoirs (e.g. formation stock tank), obstacles (e.g. reservoir damage, impediment to foreign oil companies), operational and customized risks (e.g. risks related to returns, logistics, and security (e. g. spot market price), Yield, and operational risks (e.g. market demands), well-managed production (e.g. risk resulting from statistical prediction), the Wildcat Risks Syndrome (e.g. the risk of ancillary costs, resource prices fluctuate). The authors confirmed that risk lurks in uncertainty and, if not properly planned, will have an impact on the project's profitability. For this reason, proactive preventive measures are necessary.

Idigbe and Bello (2013) investigated the difficulties faced by local business owners and the fundamental roles that will enhance Nigeria's marginal fields' value-creation contributions. The article discussed ways to maintain social and economic obligations. They found that monetizing natural gas assets and using sound business engineering in marginal fields will be best practices to create value and will have a great impact on the long-term viability of the fields. This will ensure the success of the marginal field project, particularly in the expansion of natural gas reserves, a crucial element for Nigeria's power generation.

The idea of developing marginal oilfields as a way to increase Nigeria's oil and gas reserves has not been clearly defined with a coordinated roadmap since its inception, according to Adeogun and Iledare (2015). Taking into account recoverable reserves, current fiscal terms, and economic conditions, the document redefines the concept of marginal oilfields in concrete and measurable terms. A detailed economic analysis was performed. A stochastic model was used to analyze potential scenarios as changes occur in certain input variables with the corresponding output, while a deterministic model was used to assess the profitability of the field. The findings indicated that if the government provides sufficient incentives, investing in marginal fields is thought to be worthwhile. For instance, if a reduction in the signature bonus had a positive impact on investment, while a reduction in the tax on petroleum profits and royalties had a negative impact, investment in marginal fields would be more profitable for investors. The profitability of the project was believed to be mainly influenced by the price of oil.

Ashore (2015) examined the economics of the investment matrix for the growth of Nigeria's marginal fields. Due to the drop in oil prices while the field was producing from a new facility, the marginal field taken into account in the study had a negative NPV. When derived from an existing field, however, the results demonstrate positive NPV. The outcome also demonstrated that the marginal field's operating and capital expenditure levels were too high, which decreased their profitability. Onshore and offshore financing arrangements for the development of Nigerian

marginal field underwent an optimality test in 2015 following the global economic crisis of 2014 (Ekeh and Asekomeh, 2015). Many marginal-field operators struggled to meet the financial obligations required to develop their marginal-field resources. So, some of them resorted to forming partnerships with foreign investors to cover their respective development costs. The economic viability analysis of the marginal fields was done using discounted cash flow. As listed by Ekeh and Asekomeh (2015), four scenarios were taken into consideration: the sole risk of the marginal fields, the sole risk of the foreign partner, the joint venture without the foreign partner bearing the development cost, and the joint venture with the foreign venture bearing some of the development cost. Empirical findings of their study indicated that marginal field operators are better off when they can contribute their share of development costs by sourcing funds domestically than when they are fully carried out by a foreign partner.

The NPV analysis proved that in a joint venture, the carrying of interest favors foreign partners over marginal field operators. Additionally, they thought that the effects of oil prices and the tax on petroleum profits will have the biggest effects on the NPV of any economic model. Akinwale and Akinbami (2016) used financial simulation to conduct an economic assessment of marginal oil fields. The fiscal regime and economic factors that can hinder the development of oil fields by indigenous oil companies were taken into account in their analysis. The project for a marginal oil field with post-tax NPV was found to be viable. The price of crude oil, the royalty, and the petroleum profit tax have a greater impact on NPV. It was suggested that the government conduct regular assessments of the fiscal system and formulate appropriate policies to support local players in developing the marginal oil field.

Humphrey and Dosunmu (2016) investigated the factors that contributed to the development of a marginal field by the Niger Delta Exploration and Production Company in Nigeria. To provide an explanation for the success of the development of marginal fields using Ogbelle as a case study, a detailed review of the literature on marginal oil fields was conducted. The study by Humphrey and Dosunmu identified three explanations that are pertinent to the success story: the know-how developed by the Niger Delta Exploration and Production Company through partnerships with outside parties, risk management, including the creation of joint ventures and partnerships, effective monetization of natural gas, and the role of the capital market in raising funds that aid in the development of marginal field projects. Their main finding was that risk management through the creation of partnerships, the effective use of natural resources, cooperation with third parties, and the function of the stock market were the critical success factors for the development of the Ogbelle field.

5 Marginal Field Development Strategies

The development of marginal fields in the Niger Delta of Nigeria is usually carried out in phases (Ogunsola-Saliu *et al.,* 2019). Marginal field operators can begin small to grow big and bigger with time, since marginal field investment is scalable (Gborogbosi, 2020). The strategy used is typically the one that minimizes cost the most because the goal of developing and producing such marginal resources is to make profit. Oil and gas operators of marginal resources are focused on lowering development costs because they have little control over infrastructure and oil reserves (Uwaga, 2008). Uwaga believes that by appropriate strategies for the development of marginal fields, the Nigerian economy and the overall recovery can be improved. Among the various approaches adopted by marginal field operators, Eyankware and Esaenwi (2019) developed a baseline template that would economically and technologically transform the

development of marginal gas fields in Nigeria. They opined that if the baseline development template is used in the development of marginal fields, Nigeria will witness an unprecedented increase in the much needed gas production from marginal gas fields with an evident multiplier effect on the national economy.

Akinwale (2016), while studying ways to harness science, technology, and innovation to improve marginal oil and gas field development in Nigeria, listed several ways to improve production and profitability. The approach to optimally develop the marginal gas field in Nigeria according to Akinwale includes innovative technologies such as infrasonic passive differential spectroscopy, miscible gas flooding, formation fracturing, directional and horizontal drilling, thermal recovery and acidification (Akinwale, 2016). AlBallam *et al*. (2023) added water flooding to the list of strategies to economically produce marginal fields. Okon *et al.* (2017) and Okon and Appah (2018), went further to buttress this fact by suggesting including a downholewater sink (DWS) and a downhole water loop (DWL) when the phenomenon of water conduction is anticipated as part of an integrated strategy to develop marginal fields technically and economically. Hassan *et al.,* agreeing with AlBallam *et al.,* went on to suggest that a combination of artificial lift technique will prove a technically feasible and economically attractive means to profitably develop marginal fields (Hassan *et al*., 2001).

While Dagogo *et al.* (2018) argues that infill drilling is a cost-effective means to redevelop and restart marginal and mature fields, Kalu-Ulu *et al*. (2023) agree with Hassan *et al.* (2001) on the use of artificial lift technique as a better alternative to infill drilling in marginal field redevelopment and restart of marginal wells. Kalu-Ulu *et al.* demonstrated the superiority of deploying an electric submersible pump as an artificial lift technique to redevelop a marginal field in the Niger Delta basin. Through sensitivity analysis of the ESP system and well operating conditions, they showed that ESPs can increase production from an otherwise abandoned oilfield. Furthermore, ESP systems were able to maintain a positive output regardless of field wellbore conditions, flow network properties, increased water cut, decreased reservoir pressure, and tubular changes. Finally, they showed that ESP systems can improve the production life of marginal fields in the Niger Delta, thus making the field economically viable and profitable to operate.

GEPs look at marginal field development beyond the well and rear management into the surface and overall project handling for profitable operation. GEP brought to the fore three main strategies that can bring about cost reduction in marginal field development. The use of conductor-supported platforms, the standardization of engineering designs for offshore fixed structures, and the order of offshore platforms in bulk are a few cost-cutting tactics that can be adopted in the development of marginal fields in Nigeria (GEP, 2021). On the other hand, Gborogbosi (2020) encourages early production start-up through collaboration in sharing transporting and exporting facilities, while urging marginal field investors to commence small and scale up as field development and production increases and demands so.

5.1 Minimum Facility Platform (MFP) and Conductor-Supported Minimum Offshore Structures (CoSMOS)

In conventional shallow-water development, a minimum facility platform (MFP) is used. An MFP typically comprises surface wellheads, trees, and manifolds, but does not include separation facilities. MFPs can be connected to a larger field production network or an adjacent production facility, reducing capital investment (GEP, 2021: Era and Yasin, 2021). An alternative to this is a

conductor-supported minimum offshore structure, or CoSMOS, which eliminates the need for a separate supporting jacket structure. In addition, CoSMOS offers features such as modular design, quick procurement, affordable fabrication, and simple installation. The cost of a CoSMOS platform from front-end engineering design to installation can be 30%-40% lower compared to that of a conventional jacket-supported platform (GEP., 2021). These types of installation have the ability to reduce the cost of developing marginal field facilities in several ways, including reducing the weight of steels used in facility construction, reducing the complexity of the method of fabrication, and eliminating the need for heavy lift vessels (Cameron, 2022).

5.2 Standardized Engineering Designs

Another common cost-saving strategy is the "design one, build many" approach. Here, oil companies slightly modify structural layouts to adapt to the conditions of a particular field. The approach saves on design time and labour costs. It allows fabrication to start in parallel with design tweaks, while it continues to facilitate the advance procurement of bulk materials and long-lead equipment. This reduces the lead time for new offshore platforms. The oil industry has seen many cases of the adoption of standard engineering designs to reduce the overall cost of marginal oil field development (GEP, 2021; Era and Yasin, 2021). Worley, an Australian engineering firm, has developed a new concept in wellhead platforms suitable for installation in deep-level water and to withstand rough sea conditions (GEP., 2021). Wood Group Mustang, a UK-based oil and gas consultancy, performed a similar kind of task for Anadarko Petroleum (acquired by Occidental Petroleum) for its operations at Heidelberg Field in the Gulf of Mexico. It used top-side designs from the Lucius field, also in the Gulf of Mexico, reducing the hours needed for labour, engineering, and equipment procurement.

5.3 Bundle Orders

Oil and gas operators tend to award multiple offshore platform contracts to a single engineering, procurement, and construction (EPC) contractor to reduce costs and eliminate redundancy (TNS, 2023). National oil companies award a large number of wellhead platform contracts for multiple fields or bundle the needs and contracts of multiple local operators and give the order to an EPC contractor. This approach decreases the cost per unit of platforms. For example, PTTEP, Chevron and Mitsui Oil Exploration Company awarded many wellhead platforms to the same EPC contractor under the Arthit and Bongkot expansion project (GEP., 2021; TNS, 2023). Nigerian marginal field operators can benefit from the benefits of bundling the order of long-term lead items for field development. several operators can collaborate to order, procure their facilities and fabrication from one source and combine the logistics. This will eventually reduce the procurement and execution cost, which would further make marginal field development more attractive to operators and investors.

6 Development of Some Marginal Fields in Nigeria

Nigerian indigenous firms own more than 50% of the 173 oil and gas concessions in Nigeria so far but represent less than a tenth of the 2.3 MMBPD production (Eyankware and Esaenwi, 2019). This is a paradox of ‘idle wealth’ that has denied the Nigerian government and the people the full benefit of local participation policies. More precisely, the 32 marginal fields awarded (including the five discretionary awards and the NPDC fields) cumulatively produce around

2.6% of daily oil production and 2.5% of the estimated 4,000 MMSCF gas production in the country, due in large part to the inability of indigenous firms to fully monetize assets (Lawrence, 2005; Tokunbo, 2014: Eyankware and Esaenwi, 2019). The Niger Delta oil field is one of the largest tertiary delta systems in the world and the largest African oil producing basin. It has an area of about 75,000 km^2 with numerous high-quality reservoirs stacked on top of each other and connected by growth fault-related structures. Some recently discovered marginal fields have been found in the onshore delta region (Offia, 2011). There are several marginal fields developed and in production in the Niger Delta of Nigeria (Table 1). Some of which are discussed in the following sections.

Table 1: Marginal field Operators' Reserve and Daily Rate

Operator	Field	Proven Reserve MMBBL	Rate MBOPD
Brittania-U Group	Ajapa OML90	6.69	2.2
Platform Petroleum/New Cross Petroleum LTD	Egbaoma OML38	65.78	1.8
Waltersmith Petroleum Oil LTD/Morris Petroleum	Ibigwe OML56	2.9	3.7
Midwestern Oil	Umusadege OML56	49.86	30.0
Pillar oil	Umusati/Igbuku OML56	8.9	2.7
Frontier Oil/Seven Energy	Uquo OML56	177.65	3.5
Energia/Oando	Ebendo/Obodeti OML56	15.95	4.5
Green energy	Otakikpo OML11	56.75	10.0
Seplat	Ubima OML	2.4	2.5
Eland	Opuama OML40	78.0	20.0
Naphta/Elcrest	Abiala OML40	77.0	8.6
San Leon Energy	Oza OML11		6.6
Universal Energy Resources	Stubb OML14	12.99	2.72
Shell/NNPC	Asaramatoru	28.0	-
NNPC/Mobil	Okwok	70.0	-
NNPC/Mobil	Akepo OML90	81.0	-

Sources: (Roseline and Collins, 2017; AfricaOil, 2018; Carmen, 2022; SeplatEnergy, 2022)

6.1 Otakikpo Marginal Oil Field

Approximately 60 kilometers southeast of Port Harcourt, in the Nigerian state of Rivers, is the marginal field known as Otakikpo. It is part of the OML11 oil mining lease (Figure 3). 56.75 MMBBL of oil and 70 BCF of gas are stored in its reserves. The field operator Green Energy International (GEIL, 60%) and its technical and financial partner Lekoil Oil and Gas (40%) jointly developed the field in two phases (Osten, 2012). OML11 was subcontracted to GEIL by the Shell joint venture, which is made up of the Shell Petroleum Development Company (30%), Total Nigeria (10%), the Nigerian Agip Oil Company (5%) and the Nigerian National Petroleum Corporation (55%) of the Shell Petroleum Development Company (Praveen., 2017; Mackenzie, 2023).

The field was evaluated through five reservoirs encountered after intense efforts to develop the field using three wells over a two-year period of hydrocarbon exploration. Gas and oil reserves were encountered and evaluated during the evaluation (Osten, 2012). The field study contained a thorough analysis of the field's surface and subsurface data, with a detailed field development

plan, information on the resources that were available, and the infrastructure needed to carry out operations successfully. As a result of the findings, two wells, Otakikpo-02 and Otakikpo-03 were re-entered as part of the first phase of the development plan. Three reservoirs were completed primarily by recompletions of the two wells using the dual-string completion method. The four production strings spread across the Otakikpo-02 and Otakikpo-03 wells are still producing oil (Praveen, 2017), and intend to increase to 20 MBOPD (Green, 2023).

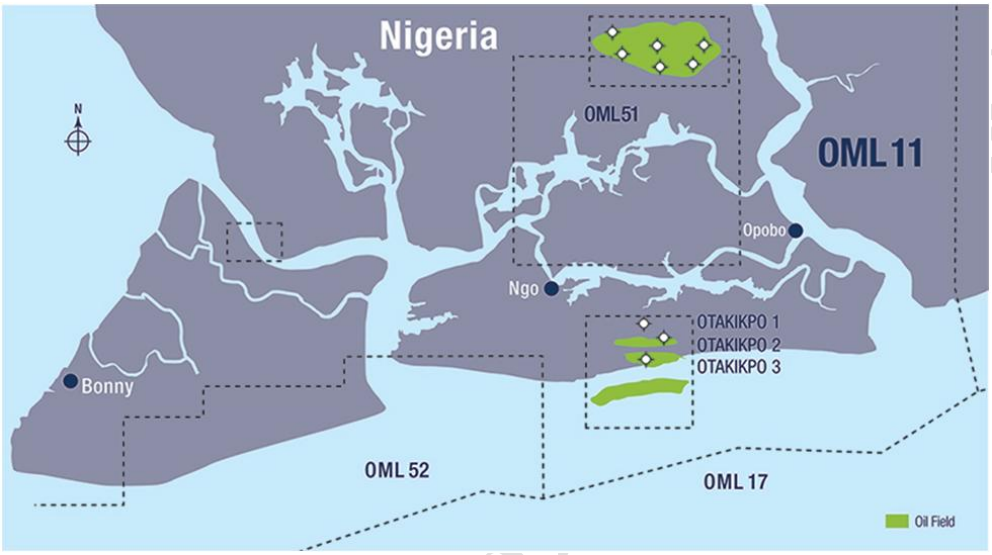

Figure 3: Otakikpo Marginal Field Location (OilfieldAfrica, 2021).

The second phase of field development involved the construction of offshore and onshore facilities, such as an extended production facility (EPF) with a capacity of 10 MBOPD, as well as a number of hydrocarbon storage tanks, a power plant, and various onshore and offshore pipelines. In addition to the above, the development of the remaining portion of the field, as well as the construction of a new central processing facility (CPF), and the drilling of seven new wells, were the main objectives of the development of phase 2. The approval secured for the second phase development includes the construction of a 1.3 MMBBL onshore terminal and a 17 km export pipeline to connect the terminal to an offshore loading bay. When completed, the offshore terminal will be the first in Nigeria in more than 50 years. It will also be the first indigenously owned and operated onshore terminal in Nigeria that would provide an efficient and cost-effective route to the market for many marginal fields in the vicinity that are stranded (guardian, 2022; Green, 2023). The CPF will initially have an 18 MBOPD processing capacity that can be increased to 35 MBOPD. The oil inlet manifold, redundant slots for additional wells, control systems, and protection and protection components were included. The facility can process light and sweet fluids from the well stream and transfer the separated stream to crude oil storage tanks, which has a combined capacity to hold 14 days' worth of gross liquid production. A barge is then used to transport the extracted oil from the site to a nearby terminal (Praveen, 2017). Oil is moved from the onshore storage tanks through an 8 km pipeline that links to another 6 km offshore pipeline that connects to the shuttle tanker. According to a crude handling agreement signed by GEIL, crude oil will be transported by a shuttle tanker to the Ima Terminal operated by Amni International Petroleum Development (Guardian, 2022).

6.2 Umusadege Field

The field is located offshore in the central north area of the Niger Delta Basin of Nigeria in OML 56. The Umusadege field is part of the conventional Onshore Delta Play (Figure 4), which is characterized by deltaic shallow marine shelf sands at intermediate depths in growth fault settling. The Umusadege field hydrocarbon reserves are contained within the Agbada sandstones from the Eocene. The Umusadege area is covered by 36 km^2 of 3D seismic data, shot in the early 1980s. The field has only one growth fault trending from WNW-ESE and a simple roll-over anticline structure, moving towards the growth fault. The Umusadege field oil-bearing sands were discovered on the down-thrown side of the fault, while the up-thrown ones are gas-prone and are over-pressured. These horizons have been interpreted in the seismic sections, and the horizons have been converted in time to depth. The surfaces have been matched to formation tops from well data. Representative cross sections showing the rollover structure at the west, central, central east, and eastern culmination are depicted (Midwestern, 2023).

An initial field development plan was submitted as one of the criteria for the field award. This has been updated twice in 2010 and 2013 from the results of additional reservoir studies carried out (Toluse *et al.*, 2016). Umusadege field reservoir units consist primarily of stacked sandstone sequences that are well organized, highly porous and permeable with high net gross ratios. The second update of the development plan in 2013 recommended drilling three horizontal and three vertical wells to develop the central and central east culminations of the field. The drilling and completion schedule, the number and placement of wells drilled so far in Umusadege field, are a function of several factors (Midwestern, 2023):

- Number of wells and rates defined from the reservoir study that culminate in the field depletion plan.
- The installed facility capacity: individual well capacities with tubulars, completion techniques, and planned artificial lift planned; and any regulatory limits on spacing and / or production rates.
- Location of wells for efficient drainage, that is, evenly spaced to contact portions of the reservoir or targeted to specific areas due to reservoir geometry, quality variations, or invading water or gas.
- The first four horizontal wells were drilled in Umusadege to:
    - Expose the well to a more lateral extent of the reservoir.
    - Achieve higher rates with fewer wells.
    - Minimize conduction of gas and/or water.

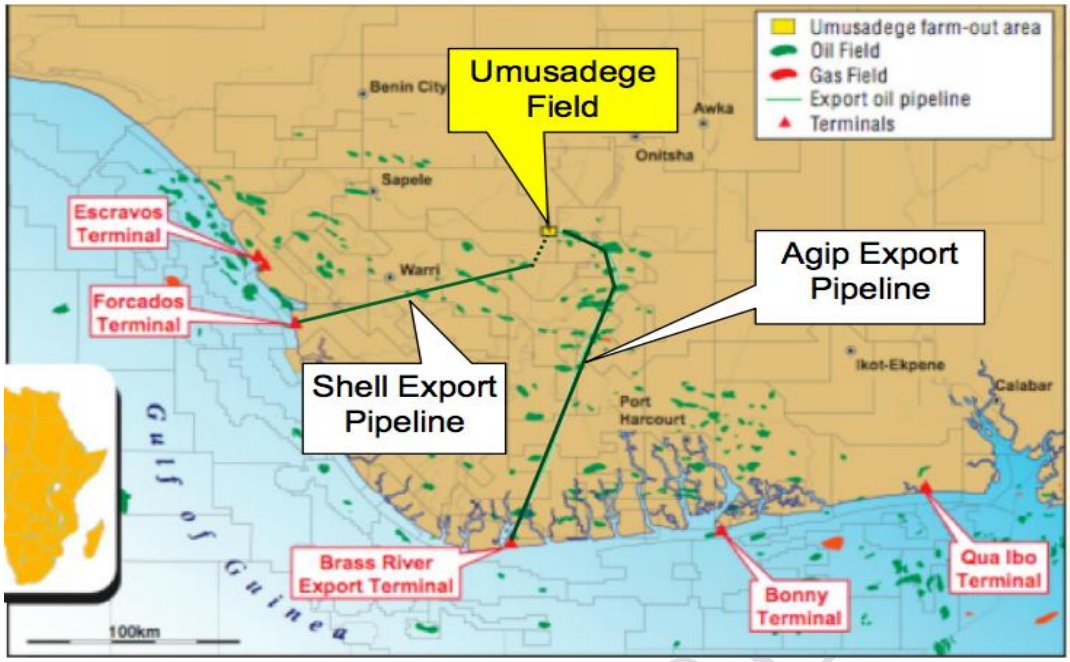

Figure 4: Umusadege Marginal Field Location (Investorvillage, 2012).

The Umusadege field in OML 56 was originally operated by EPNL (Elf petroleum Nigeria limited). EPNL drilled a total of 3 wells between 1974 and 1978, proving the existence of oil in 13 sands with a total estimated reserves of about 42MMBBL that were considered marginal and abandoned. The field was awarded to Midwestern Oil and Gas PLC (MWOG) at -70% and SunTrust Int. – 30% in 2003, Midwestern re-entered Umu-1 in 2007/2008 and completed the well in two sands XIIa and XIIb and commenced production at about 2 MBOPD. MWOG has drilled a total of 18 wells (including 4 horizontal wells and 2 water disposal wells) between 2007 and 2016 and proved the existence of oil in 26 sands and gas condensate in 3 sands (Toluse *et al.*, 2016; Midwestern, 2023). The maximum efficient rate (MER) and bottom hole flow/build-up surveys are conducted immediately after each well completion, and when required to investigate changes in reservoir conditions, well productivity, and to increase general understanding of the field. Static bottom-hole pressure surveys on each production interval are conducted at least once a year (Toluse *et al.*, 2016).

Umusadege Field was developed successfully using the aforementioned methods, which combined new technologies with traditional reservoir and production strategies. During a seven-year period, daily oil production increased from 2,000 barrels per day at the time of the first well reentry to approximately 30,000 barrels per day. At present, the Umusadege field has a state-of-the -art central processing facility, the first of the kind for a marginal field in Nigeria and Africa. An 80 MBOPD group gathering facility has been built to alleviate the infrastructure challenges facing marginal field production efforts. In the same vein, a 110MBBL steel-welded storage tank has been built to mitigate against production deferment and losses attributable to pipeline outages as a result of vandalism and theft (Midwestern, 2023; Suntrust, 2023). The development of the Umusadege field has taken it a step further by exporting hydrocarbon produced through two export pipelines. The TransForcados pipeline, which connects the Umugini pipeline and the AGIP export pipeline as a brass river terminal. The Umugini pipeline is a pipeline of 51.4 km by 12 inches with a capacity of 45MBOPD. The ability to transport and export oil through two

independent terminals significantly reduces the risk of well shutdown and production deferment due to pipeline inaccessibility (Suntrust, 2023). The development of the Umusadege field demonstrates how the value of any hydrocarbon asset can be increased in a way that is economical, secure, and environmentally friendly with the proper application of the essential components of the reservoir, material, and human management.

6.3 Ubima Field

Ubima is the outer field of OML 17, about 40 km north of Port Harcourt. It was discovered onshore by Shell in 1963 but was not developed. In 2002, it was transferred to All Grace Energy. In 2014, E-Land Oil & Gas acquired a 40% stake and a technical stake (Eland, 2014). Elan was thought to be unable to develop the Ubima field, but in August 2018, the Ubima-1 well was reintroduced, and flow tests were conducted at various reservoir levels with initial gross rates of up to 2.5 MBPD. Dual sequences were completed for the target oils of four-layer wells: D1000, E1000, E2000 and F7000. According to a study published by AGR TRACS in April 2016, Ubima-1 has total oil reserves of 2.4 MMBBL. Based on the complete exploitation of the oil fields, estimated resources would be 20.6 MMBBL (1C), 31.1 MMBBL (2C) and 66 MMBBL (3C) (AfricaOil, 2018) In November 2019, Seplat acquired E-Land Oil & Gas for $440 million. The Eland chief executive officer believes that the debt secured against the enlarged asset base will help the company move quickly into developing the asset to early production, thus generating strong cash flow. The Ubima field began production in a zero-gas flare facility that was designed to meet federal government policies on local content development and community growth aspirations (GraceEnergy, 2019).

6.4 Stubb Creek Conventional Oil Field

The field is located in the southeast of Nigeria close to the Cameroun border. The field is located in block Stubb Creek (OML 14). Stubb Creek is a conventional oil field that currently produces oil and is operated by Universal Energy Resources. China Petroleum and Savannah Energy are the landowners. Sinopec, the Chinese company, ventured into the field as a technical partner to help deliver field development. 62.5% of the asset was sold to Seven Energy around 2009/2010 in a move to raise the much-needed capital to begin field development. Through an early production development strategy, the conventional Stubb Creek field was launched in 2015. (MacKenzie, 2023) With peak production in 2022, the Stubb Creek conventional oil field recovered 33.24% of its total recoverable reserves. Approximately 2.72 MBPD of crude oil and condensate were produced at their highest level. Production will continue until the field hits its economic limit in 2072, according to economic projections. The field is expected to produce 12.99 MMBOE, which is made up of 12.99 MMBBL of crude oil and condensate (Carmen., 2023).

6.5 Oza Field

The Oza field, located in the northwest corner of OML11 in Abia State, which is 30 km southwest of Port Harcourt, is a 20km^2 concession (Figure 5). The field transports crude oil through the Trans Nigerian Pipeline (TNP) to the Bonny Export Terminal for export. The pipeline also serves as shared ferries between the Isirmi, Obeakpu, Afam, Obigbo, and Umuosis

fields (Morgan, 2020). The Oza reservoir had a high gas-oil ratio, but through well sidetracks, sustainable oil production was ensured. Due to declining oil production and rising GORs, the field was abandoned by Shell in 1983 after producing more than a million barrels of oil (Nikola *et al*., 2021). The field farm-out is currently shared by three parties of Millennium, Hardy, and Emerald at 60%, 20%, and 20%, respectively, following a farm-out to Hardy (in 2006) and Emerald (in 2008). To provide the technical, financial, and operational support required for the development of the field, Decklar Petroleum entered into a conditional subscription agreement with Millennium in April 2019 on behalf of the joint venture partners of the field.

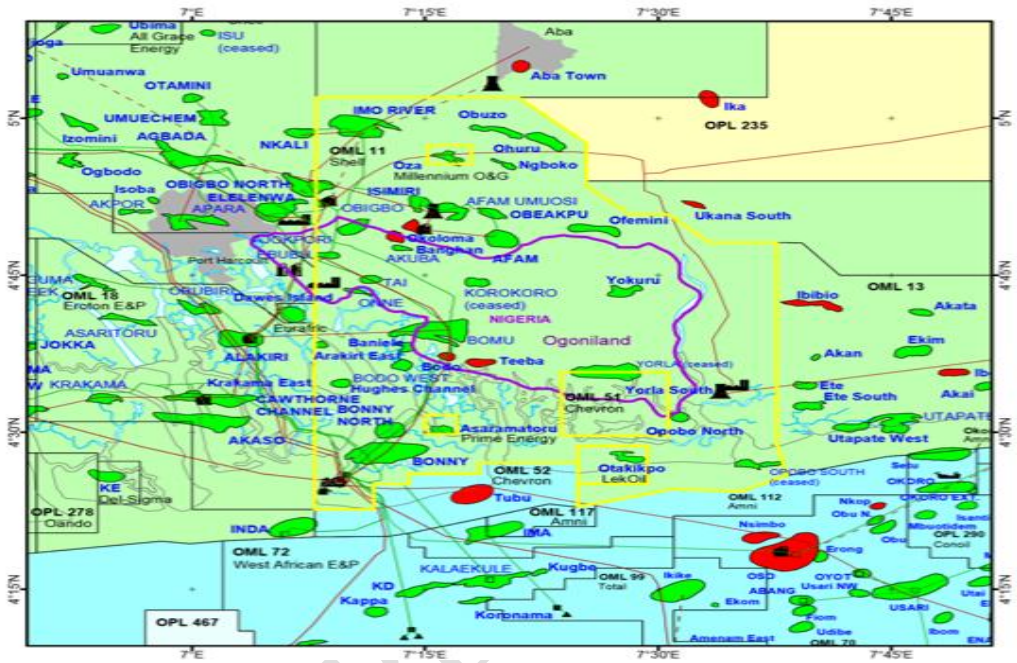

Figure 5: Oza Marginal Field Location (Alian, 2023).

According to the terms of the agreement, Decklar will cover all capital expenses up front and, in return, takes 80% of distributable funds until all capital investment is recouped (Nikola *et al*., 2021; Oladipo, 2021; Alian, 2023). The first phase of field redevelopment started with reentry and reactivation of Oza-1 as a multizone producer, followed by a drilling of another horizontal well to increase field production, since there was excess capacity in export pipelines and production facilities. This idea is in line with the concept of starting small and scaling out later, as proposed by Gborogbosi (2020). From the well completion and well connection activities in the first phase, the proven reservoir flow test was performed at a stabilized rate of 2.5MBPD, which was higher than anticipated. During the same time, there was an initial gas flow of approximately 10.3 MMSCF of natural gas per day (Oladipo, 2021).

Additionally, Decklar plans to upgrade the facilities to accommodate anticipated production increases and replace temporary facilities with permanent ones, which could result in lower operating costs. The anticipated increase in production is expected to come from the second phase development strategy. The second phase of field development included the drilling of additional 4 to 5 new development wells, more infill drilling, and the tie-in of wells to existing infrastructure (Nikola *et al*., 2021). Decklar, like other marginal field operators, has continued to work toward the implementation and operationalization of the petroleum industry act in the Oza

field facility and other facilities of interest (KPMG, 2022; Nikola *et al*., 2021). Decklar has continued to support the federal government's aspiration of indigenization and domestic development by supporting and supplying crude feeds from local refineries such as Edo Refinery and Petrochemicals Company Limited and Duport Midstream Company Limited (Alian, 2023).

7 Remarks from the Review

This paper covered the review of existing strategies in the development of marginal fields in Nigeria with reference to some fields located in the Niger Delta basin. The review looked at the challenges, economic viability, and the role of the federal government in incorporating the contributions of marginal fields to the national reserve and oil production output. Also, the previously reported marginal field development and management practices in the Niger Delta oilfield was x-rayed. From the review the following inferences were drawn:

7.1 Confidence in Project Implementation

Confidence of marginal field operators in project implement and execution has improved since the formation of the new regulatory body, Nigerian Upstream Petroleum Regulatory Commission, and the passing of the Petroleum Industry Act. These two accomplishments by the federal government of Nigeria have demonstrated the government's commitment and seriousness in the development of the marginal fields in Nigeria to increase the existing reserve, improve production capacity and encourage communities and national development through indigenization. With these, operators are confident of the future of the marginal fields in Nigeria and are willing to undertake calculated business risks with commitment and assurance of recouping their investment in the Nigeran oil and gas environment.

7.2 Development and Sharing of Best Practices

One of the observations from the review is lack of appropriate collaboration in sharing of best practices between the marginal field operators. Collaboration should be encouraged and promoted through the leadership of the marginal field companies and their partners. Collaboration in knowledge management is healthy for the management of marginal fields in Nigeria. Reasonable developmental data and information should be shared among the operators to avoid a situation of reinventing the wheels the marginal field development. NUPRC should encourage the collaboration among the marginal fields and harness the best practices from successful operators to develop succinct guidelines on how to successfully develop and profitably operate marginal fields in Nigeria.

7.3 Partnerships of Shared Vision

Following the first marginal fields award in 2003, partnerships were foisted on marginal field operators by the federal government. The intended development was absent largely because such forced partnerships was poised with distrust and cautious commitment until the next round of marginal fields bidding in 2020 and concluded in 2021. Following this award and free choice in selecting and in choosing partners, operators have been able to search and select their own partners based on their individual preferences based on financial and developmental needs. Partnerships with shared vision and common interest come up with committed plans and strategies to execute the marginal field developmental projects.

7.4 Additional Solutions

So many researchers have provided or proposed solutions to challenges faced by marginal field operators in Nigeria. Irrespective of the solutions provided and implemented in some marginal field developments, there are still opportunities for improvement to maximize the resources and reserves of the marginal field in Nigeria. Some of the additional solutions for some the fields are as tabulated below:

Table 2: Additional solutions to marginal fields challenges

S/N	Authors	Field	Reported Problem	Suggested Solutions
1	Toluse *et al.*, 2016	Umusadege	Declining Reservoir pressure.	Use of appropriate waterflooding and or chemical flooding placed at the boundaries of the reservoir for efficient sweep.
2	Toluse *et al.*, 2016	Umusadege	Limited Process Facility Capacity which limits daily production rate.	Surface multi-centrifugal pump stations can be used to transport produced hydrocarbon from header to nearest facility with higher processing capacity. This will ensure no available hydrocarbon is left unproduced.
3	Dagogo *et al.*, 2018	Sango	Use of infill drilling to arrest rapid decline in Production.	Use of Artificial lift ESP technique will reverse the decline and prolong the field life.
4	(Oyakhire and Omeke, 2017)	X-Field	Poor production data recording	Introduce digital oilfield tools for realtime, and remote data gathering and control devoid of human interference.
5	(Oruwari, 2021)	Asuokpu/Umutu	Excess gas flaring	Excess should be monetized for domestic use and power generation. Power generation and distribution is currently within

				marginal field operators reach.

8 Conclusion

Marginal field development in Nigeria may have shifted in scope and definition following the introduction of the Petroleum Industry Act; however, the end goal remains the same. With the increasing reserve and production capacity of the Nigerian oil and gas sector, the Nigerian Upstream Petroleum Regulatory Commission now supervises the biding, awarding, and voluntary farm-out of petroleum producing licences. The Petroleum mining lease and production licence operators prefer to develop their fields in phases. The reason is lack of funding to undertake the whole field project development at once or lack of required expertise or guiding framework. Therefore, the proper screening and selection of farm partners to finance and develop marginal fields through development and production incentives, such as early production and sustained production incentives. In addition, the federal government and the commission should conduct regular fiscal assessments of the performance of the petroleum producing lease licence operators to understand their performance, to form appropriate policies that would ensure maximal utilization of the resources for optimal and effective contributions to local and national development.

Recent success stores and the track record of experienced locals retiring from meritorious companies in translating reserves to cashflow are steadily improving the appetite of local banks for marginal field development financing. Hence, collaboration is quite important and should be promoted through the leadership of all petroleum producing licence owners and petroleum mining lease operators. Through collaborations, lessons learnt can be shared among the respective field operators on how best to handle the seemingly challenging factors faced by marginal field operators in a cost-effective and timely manner. Modalities on information sharing and utilization should be developed and communicated among the various marginal field operators and the relevant federal government representative bodies.

Most of the daily crude production is provided by mature oil fields. Unfortunately, oil production from this kind of field and resources are on the decline leading to abandonment. This requires a new and cost-effective approach to make marginal fields productive and economically viable. Therefore, a combination of sound economic evaluation of marginal fields developmental project and the implementation of innovative technologies for both subsurface well completion level and surface facilities will not only improve the reserves of Nigeria's marginal fields as envisaged by the federal government but will also lead to an increase in the production capacities of the various field operators as well as the state. The costs associated with the development and production of the fields will be significantly reduced while the production lifespan of the fields is extended. This will make the development of Nigerian marginal fields profitable and attractive to both local and foreign operators and investors, as well.

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Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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