Shodhshauryam, International Scientific Refereed Research Journal
© 2022 SHISRRJ | Volume 5 | Issue 4 | ISSN : 2581- 6306

A Framework for Emission Monitoring and Optimization in Energy-Intensive Floating Oil and Gas Production Systems

Andrew Tochukwu Ofoedu[1], Joshua Emeka Ozor[2], Oludayo Sofoluwe[3], Dazok Donald Jambol[4]
[1]Shell Nigeria Exploration and Production Company, Nigeria
[2]First Hydrocarbon, Nigeria
[3]TotalEnergies Nigeria
[4]Shell Petroleum Development Company of Nigeria Ltd
Corresponding Author : andrewofoedu@yahoo.com

Article Info
Volume 5, Issue 4
Page Number : 189-207

Publication Issue :
July-August 2022

Article History
Accepted : 01 July 2022
Published : 20 July 2022

Abstract - Floating oil and gas production systems, including Floating Production Storage and Offloading (FPSO) units and Floating Liquefied Natural Gas (FLNG) facilities, play a crucial role in offshore hydrocarbon extraction. However, these systems are highly energy-intensive and contribute significantly to greenhouse gas (GHG) and pollutant emissions, posing environmental and regulatory challenges. This presents a comprehensive framework for real-time emission monitoring and optimization tailored to the complex operational environment of floating production units. The framework integrates advanced sensor technologies for continuous monitoring of key emission species such as CO_2, CH_4, NO_x, and SO_x, coupled with robust data acquisition and transmission protocols designed to handle the harsh offshore conditions. Data fusion techniques are employed to combine sensor outputs with operational logs and process simulations, ensuring data accuracy and reliability despite noise and missing information. Central to the framework is an emission optimization module that leverages thermodynamic and equipment performance models alongside artificial intelligence and machine learning algorithms. This module supports multi-objective optimization strategies, balancing emission reduction goals with production efficiency and operational constraints. Key optimization approaches include predictive control, load management, fuel switching, and flare minimization, enabling operators to make informed decisions that reduce environmental impact without compromising system performance. The framework's efficacy is demonstrated through a detailed case study of a representative FPSO, showcasing significant potential for emission reduction and improved energy efficiency. Sensitivity analyses highlight the robustness of the approach under varying operational conditions and uncertainties. Finally, the review discusses practical considerations for integrating the framework with existing onboard control systems, addressing cybersecurity and operator training needs. Future directions include expanding the framework to incorporate carbon capture technologies and autonomous optimization capabilities. This framework provides a scalable and adaptable solution to support floating production operators in meeting increasingly stringent environmental regulations while optimizing operational performance, thus contributing to the sustainable development of offshore oil and gas resources.

Keywords: Framework, Emission, Monitoring, Optimization, Energy-Intensive, Floating Oil And Gas Production Systems

1. Introduction

Floating production systems, such as Floating Production Storage and Offloading units (FPSOs) and Floating Liquefied Natural Gas facilities (FLNGs), are vital assets in offshore oil and gas extraction, particularly in deepwater and ultra-deepwater environments (Awe, 2017; Oyedokun, 2019). These systems are designed to extract, process, store, and offload hydrocarbons directly at sea, eliminating the need for extensive fixed platforms or pipelines to shore. FPSOs are versatile units capable of handling crude oil production, storage, and offloading, while FLNGs specialize in processing and liquefying natural gas for transport (Awe *et al.*, 2017; ADEWOYIN *et al.*, 2020). Due to their remote and complex operational environments, these floating systems are inherently energy-intensive, relying heavily on onboard power generation for processing equipment, gas compression, heating, and other auxiliary systems (Akpan *et al.*, 2017; OGUNNOWO *et al.*, 2020).
The importance of monitoring greenhouse gas (GHG) emissions and other pollutants from these floating units has escalated in recent years amid growing environmental concerns and tightening regulatory requirements (Omisola *et al.*, 2020; ADEWOYIN *et al.*, 2020). Emissions from offshore facilities contribute significantly to the carbon footprint of hydrocarbon production, with CO_2, methane (CH_4), nitrogen oxides (NO_x), and sulfur oxides (SO_x) among the primary pollutants. Effective monitoring is critical not only for regulatory compliance but also for environmental stewardship and operational optimization (Solanke *et al.*, 2014; Chudi *et al.*, 2019). Real-time emissions data enable operators to identify inefficiencies, reduce wasteful energy consumption, and mitigate environmental impact, contributing to sustainable offshore production (Magnus *et al.*, 2011; Chudi *et al.*, 2019).

Despite the critical need for emissions oversight, floating production units face substantial challenges in achieving effective emission control (Ajiga, 2021; Odio *et al.*, 2021). The high energy consumption of FPSOs and FLNGs arises from continuous operation of power-intensive systems such as gas turbines, compressors, and flaring systems. These systems operate in harsh offshore environments, with limited opportunities for maintenance or operational intervention (Awe *et al.*, 2017; Akpan *et al.*, 2019). Furthermore, the complexity and variability of production processes lead to fluctuating emission profiles, complicating efforts to monitor and control emissions accurately (Adesemoye *et al.*, 2021; ADEWOYIN *et al.*, 2021).

Currently, there is limited visibility into real-time emissions due to fragmented sensor deployments, data acquisition limitations, and integration challenges with control systems (OGUNNOWO *et al.*, 2021; Ogunnowo *et al.*, 2021). Existing monitoring approaches often rely on periodic manual sampling or infrequent data reporting, which fails to capture transient emission events or provide timely actionable insights (Okolo *et al.*, 2021; Ojika *et al.*, 2021). Consequently, operators struggle to optimize energy use and emissions proactively, increasing operational costs and environmental risks (ADEWOYIN *et al.*, 2021; Onyeke *et al.*, 2022).

In response to these challenges, this aims to develop a comprehensive framework for real-time emission monitoring and optimization specifically tailored for energy-intensive floating oil and gas production systems (Daraojimba *et al.*, 2021; Orieno *et al.*, 2021). The framework seeks to integrate advanced sensor networks, robust data acquisition methods, and sophisticated data processing algorithms to provide accurate, continuous emission measurements. Additionally, it incorporates optimization strategies leveraging process modeling and artificial intelligence to balance emission reduction with operational efficiency (Onaghinor *et al.*, 2021; Mustapha *et al.*, 2021). The ultimate goal is to empower operators with actionable intelligence that supports sustainable production, regulatory compliance, and cost-effective energy management.

2. Methodology

To conduct a comprehensive review on emission monitoring and optimization in energy-intensive floating oil and gas production systems, a systematic literature search was performed following the PRISMA guidelines. Relevant studies were identified through electronic database searches including Scopus, Web of Science, and IEEE Xplore, using a combination of keywords such as "emission monitoring," "optimization," "floating oil and gas production," "energy-intensive systems," and related terms. The search was restricted to articles published in English within the last 15 years to capture the most recent advancements in this rapidly evolving field.

After retrieving the initial set of articles, duplicates were removed using reference management software. Titles and abstracts of the remaining articles were screened for relevance against predefined inclusion criteria focused on studies addressing emission quantification, monitoring frameworks, optimization techniques, and energy management specifically within floating oil and gas platforms. Studies that did not directly relate to these topics or those focusing solely on onshore systems were excluded.

Full-text versions of the shortlisted articles were then assessed for eligibility, ensuring that the selected studies provided empirical data, methodological frameworks, or case studies pertinent to emission monitoring and optimization. Articles lacking sufficient methodological detail or those that were purely conceptual without practical validation were excluded to maintain quality and applicability.

Data extraction was conducted systematically from the eligible studies, capturing key information such as monitoring techniques used, types of emissions addressed, optimization methods applied, system configurations, and reported outcomes in terms of emission reductions or energy savings. The quality and risk of bias of included studies were evaluated based on transparency of methodology, robustness of data, and reproducibility of results.

The synthesis of findings was conducted narratively and thematically, focusing on identifying common approaches, technological trends, challenges, and gaps in current emission monitoring and optimization practices in floating oil and gas production systems. This methodical approach aimed to provide a comprehensive and reliable framework to guide future research and industrial applications in reducing environmental impact within this sector.

2.1 System Overview

Floating production systems play a crucial role in offshore oil and gas extraction, particularly in deepwater and ultra-deepwater environments where traditional fixed platforms are impractical. These systems are complex installations that encompass multiple subsystems, each with significant energy demands and associated emission sources (Adewoyin, 2021; Dienagha *et al.*, 2021). Understanding the structure and operation of these floating systems, the emissions generated, and the regulatory environment that governs their operation is essential for developing effective emission monitoring and optimization frameworks.

Floating production systems can be broadly classified into several types, including Floating Production Storage and Offloading units (FPSOs), Floating Storage and Offloading units (FSOs), Tension Leg Platforms (TLPs), and Spar platforms. FPSOs are among the most widely used and versatile, capable of producing, processing, storing, and offloading hydrocarbons. These systems integrate energy-intensive subsystems essential to their operation. Power generation onboard is typically accomplished through gas turbines or diesel engines, which supply electricity to the entire facility. Gas compression systems are employed to re-inject or export produced gas, often requiring significant mechanical energy. Water injection subsystems maintain reservoir pressure and enhance hydrocarbon recovery but also consume substantial power. Additionally, flaring systems are used to safely dispose of excess hydrocarbons or gases that cannot be processed or stored, acting as a critical safety measure but a notable source of emissions (Chudi *et al.*, 2021; Awe, 2021).

Emissions from floating production systems originate from various sources, primarily linked to combustion processes and system leaks. Combustion sources such as gas turbines and diesel engines are major contributors to carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter. Gas turbines, favored for their reliability and power-to-weight ratio, burn natural gas or other hydrocarbons to generate electricity but emit greenhouse gases and pollutants as byproducts. Diesel engines, often used as backup or auxiliary power sources, also contribute substantially to emissions. Beyond combustion, venting and flaring are significant contributors to methane (CH_4) and CO_2 emissions. Venting involves the intentional release of unburned hydrocarbons directly into the atmosphere, usually during maintenance or operational upsets (Okolo *et al.*, 2022; Nwulu *et al.*, 2022). Flaring combusts these gases but still results in CO_2 emissions and incomplete combustion can generate methane, a potent greenhouse gas. Fugitive emissions, which occur due to leaks in valves, seals, connectors, and other equipment, present a stealthy but critical source of hydrocarbon loss and environmental impact. These leaks are difficult to detect but can cumulatively account for substantial emissions over time.

The operational and regulatory context surrounding emissions from floating production systems has evolved significantly in recent years, reflecting increasing global awareness of climate change and environmental protection. International frameworks such as the International Maritime Organization's (IMO) regulations, including the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), set standards for energy use and emissions in maritime and offshore operations. The European Union's Monitoring, Reporting, and Verification (EU MRV) regulation mandates the annual monitoring and reporting of CO_2 emissions from ships, influencing offshore floating units as well. Additionally, industry initiatives like the Oil and Gas Methane Partnership (OGMP) focus specifically on methane emission reductions across the oil and gas value chain, encouraging transparency and improved measurement techniques (Ogunwole *et al.*, 2022; Esan *et al.*, 2022). These regulations and initiatives underscore the need for integrated emission monitoring frameworks that do not operate in isolation but are closely tied to operational management.

The integration of emission monitoring systems with operational management is critical for optimizing energy use and minimizing environmental impact. Real-time monitoring technologies, such as continuous emission monitoring systems (CEMS), sensor networks, and advanced analytics, provide operators with actionable data on emissions and equipment performance. This information enables proactive decision-making, such as adjusting fuel consumption, optimizing compressor operation, scheduling maintenance to reduce fugitive emissions, and improving flaring efficiency. Furthermore, integration facilitates compliance with regulatory requirements by automating reporting and ensuring transparency. The adoption of digital twins and predictive models enhances this integration, enabling simulation and optimization of energy and emission profiles under varying operational scenarios (Ojika *et al.*, 2022; Uzozie *et al.*, 2022).

Floating production systems are intricate platforms with multiple energy-intensive subsystems that collectively generate significant emissions through combustion, venting, flaring, and leaks. These emissions are subject to an evolving landscape of regulatory standards and industry initiatives aimed at curbing greenhouse gases and pollutants. To meet these challenges, there is a critical need to embed emission monitoring within operational management frameworks, leveraging advanced technologies to optimize energy use, reduce emissions, and ensure regulatory compliance (Ojika *et al.*, 2022; Uzozie *et al.*, 2022). This integrated approach forms the foundation for sustainable offshore oil and gas production in an increasingly carbon-conscious world.

2.2 Emission Monitoring Architecture

Effective emission monitoring in energy-intensive floating oil and gas production systems requires a robust and integrated architecture that encompasses sensor infrastructure, data acquisition and transmission, and data fusion and validation processes as shown in figure 1(Onaghinor *et al.*, 2022; Ogunwole *et al.*, 2022). This outlines the critical components of such an architecture tailored to the unique challenges of offshore floating production units like FPSOs and FLNGs.

The foundation of an emission monitoring system lies in the deployment of accurate and reliable sensors capable of detecting key greenhouse gases (GHGs) and pollutants. The primary gases of interest on floating production systems include carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), and sulfur oxides (SO_x). Each of these gases originates from various onboard processes such as combustion in gas turbines and engines, flaring operations, venting, and fugitive leaks.

For CO_2 monitoring, nondispersive infrared (NDIR) sensors are commonly employed due to their sensitivity and durability in harsh offshore environments. Methane sensors often use tunable diode laser absorption spectroscopy (TDLAS) or catalytic bead sensors to detect low concentrations with high specificity. Nitrogen oxides are typically measured using chemiluminescence detectors, which provide selective and real-time quantification of NO and NO_2 components. Sulfur oxides, particularly SO_2, are monitored through ultraviolet fluorescence sensors that offer rapid response and high accuracy (Adedokun *et al.*, 2022; Komi *et al.*, 2022).

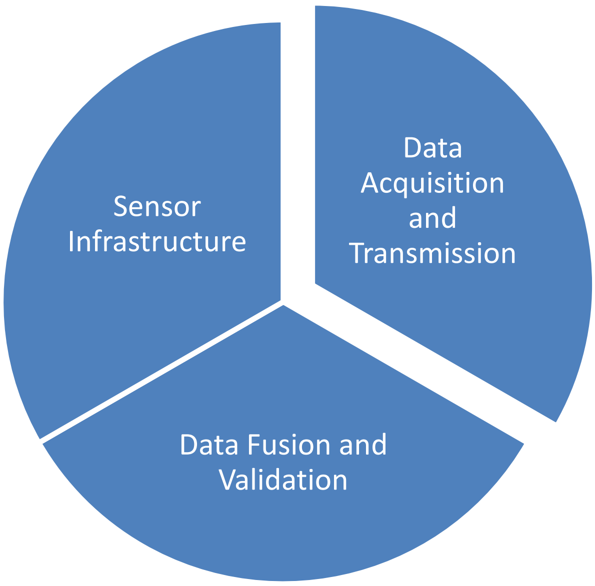

Figure 1: Emission Monitoring Architecture

Sensor placement is critical for capturing representative emission data. Sensors are strategically installed at known emission points such as exhaust stacks of gas turbines and engines, flare headers, vent lines, and potential leak-prone areas like valve seals and pipeline joints. Integration with topside process control systems allows sensors to be connected to the distributed control system (DCS) or supervisory control and data acquisition (SCADA) systems for centralized monitoring. Sensors are housed in protective enclosures designed to withstand corrosive saltwater atmospheres, temperature fluctuations, and mechanical vibrations typical of offshore operations (Ubamadu *et al.*, 2022; Onyeke *et al.*, 2022).

Given the dynamic nature of floating production environments, real-time data acquisition is essential for timely detection and mitigation of emission events. The monitoring architecture incorporates continuous data logging from multiple sensors, capturing high-frequency measurements that reflect transient emission fluctuations.

Edge computing devices are deployed close to sensor clusters to preprocess data locally, performing initial filtering, anomaly detection, and compression. This reduces latency and bandwidth requirements for transmitting data to central servers or cloud platforms. Edge computing also enables autonomous local decision-making in case of connectivity loss.

Connectivity presents a significant challenge on floating systems, as data must be transmitted reliably over potentially unstable networks. Wired Ethernet and fiber-optic cables provide high-speed communication within the topside infrastructure, while wireless technologies such as Wi-Fi or 4G/5G may be used for less critical sensor nodes or for redundancy. Satellite communication is often necessary for offshore facilities far from shore, though it introduces latency and cost constraints. The system architecture must incorporate robust protocols to handle intermittent connectivity and ensure data integrity during transmission.

Raw sensor data alone often provide an incomplete or noisy picture of emissions due to environmental interferences, sensor drift, and operational fluctuations. To enhance accuracy, the monitoring framework employs data fusion techniques that combine sensor readings with complementary information from operational logs and process simulations (Achumie *et al.*, 2022; Onyeke *et al.*, 2022).

Operational logs include data on equipment status, fuel consumption, production rates, and maintenance activities. Integrating these logs with sensor data provides contextual insights, enabling the correlation of emission spikes with specific process events or equipment malfunctions. Process simulations, often based on thermodynamic and fluid dynamic models of the production system, offer predictive estimates of expected emissions under given operating conditions. Comparing sensor data with simulation outputs helps identify anomalies and validate sensor measurements.

Handling noise and missing data is critical for maintaining system reliability. Noise filtering algorithms, such as Kalman filters or wavelet transforms, are applied to smooth sensor signals and remove outliers. Missing data, which may result from sensor faults or communication interruptions, are addressed through imputation methods using interpolation or machine learning models trained to predict missing values based on historical patterns.

Regular sensor calibration is vital to counteract drift and degradation over time. Calibration routines are automated where possible, using reference gases or internal sensor diagnostics, and are supplemented by manual checks during scheduled maintenance. Calibration data are incorporated into data processing workflows to adjust sensor outputs dynamically, ensuring long-term measurement accuracy.

The emission monitoring architecture for floating oil and gas production systems integrates advanced sensor technologies with sophisticated data acquisition, transmission, and fusion techniques (Nwulu *et al.*, 2022; Elete *et al.*, 2022). This comprehensive approach ensures accurate, real-time emissions data essential for effective environmental management and operational optimization in challenging offshore environments.

2.3 Emission Optimization Framework

In floating oil and gas production systems, achieving emission reductions while maintaining operational efficiency requires a sophisticated optimization framework that integrates detailed energy and process modeling with advanced optimization algorithms and practical operational strategies as shown in figure 2. This details the core components of such a framework designed to minimize greenhouse gas and pollutant emissions without compromising production targets.

A fundamental aspect of emission optimization lies in accurately modeling the energy consumption and process dynamics of critical subsea and topside systems. Thermodynamic models are employed to characterize key equipment such as gas compressors, separation units, and power generation turbines. Similarly, separation units—used to segregate oil, gas, and water phases—are modeled using mass and energy balances alongside phase equilibrium calculations, enabling the estimation of energy demands and potential emission contributions linked to operating parameters like temperature and pressure (Nwulu *et al.*, 2022; Elete *et al.*, 2022).

Beyond individual equipment, system-level performance modeling aggregates these component models into comprehensive digital twins—virtual replicas of the physical asset. Digital twins incorporate real-time data feeds, allowing dynamic simulation of the floating production system's behavior under different scenarios. These models help predict emissions and energy use as functions of operational changes, providing a testbed for optimization algorithms and what-if analyses. By accurately reflecting the complex interplay between equipment, process variables, and environmental conditions, digital twins serve as a critical foundation for informed decision-making.

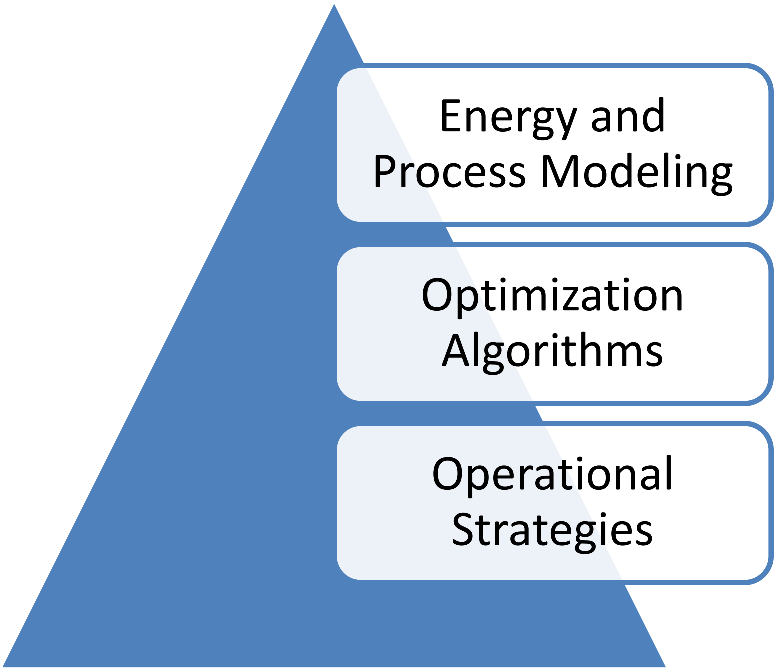

Figure 2 : Emission Optimization Framework

The optimization challenge is inherently multi-objective, balancing the goals of emission reduction, energy efficiency, and production reliability. Emission minimization often conflicts with maximizing hydrocarbon output, necessitating algorithms that can navigate trade-offs and identify optimal operating points.

Multi-objective optimization techniques such as Pareto-based evolutionary algorithms or weighted-sum approaches are applied to this problem. These methods generate sets of solutions that offer different balances between emissions and production, enabling operators to select strategies aligned with priorities such as regulatory compliance or profitability.

Artificial intelligence (AI) and machine learning (ML) augment these classical optimization methods by enabling predictive control and adaptive decision support. Supervised ML models predict equipment performance degradation or fault likelihood, informing maintenance scheduling that prevents inefficient operation and excessive emissions (Nwulu *et al.*, 2022; Ajiga *et al.*, 2022). Integrating AI-driven forecasting with optimization algorithms creates a responsive system capable of real-time adjustment to changing conditions and disturbances.

To translate optimization results into actionable measures, several operational strategies are implemented to reduce emissions practically; Load Shedding, this involves selectively reducing or temporarily shutting down non-critical equipment during peak demand or high emission periods. By prioritizing essential processes, load shedding minimizes energy consumption and emissions without significant production loss. Scheduling, production schedules and equipment runtimes are optimized to avoid operating under suboptimal conditions that lead to excess emissions. For instance, gas compressors may be cycled or throttled based on forecasted production rates and energy prices, optimizing their duty cycles for minimal emissions.

Fuel Switching, where feasible, switching to cleaner fuel sources, such as blending natural gas with lower-carbon alternatives or using hydrogen-enriched fuels, reduces the carbon intensity of combustion processes on floating units. The optimization framework evaluates trade-offs in fuel costs, availability, and emission reductions. Flare Minimization, flaring is a major source of emissions on floating production systems, often used as a safety release or during process upsets. Operational strategies focus on improving flare gas recovery systems, reducing unnecessary flaring through predictive maintenance, and optimizing process parameters to maintain stable operation within flare limits (Giuliani *et al.*, 2019; Asadi *et al.*, 2021).

Together, these strategies form an integrated operational toolkit guided by the optimization framework. By continuously monitoring system states and forecasting emissions, operators can implement these tactics dynamically, achieving sustained emission reductions aligned with production goals.

The emission optimization framework combines detailed thermodynamic and equipment modeling with advanced multi-objective algorithms and AI-driven control to manage the complex trade-offs inherent in floating oil and gas production. Coupled with practical operational strategies like load shedding and flare minimization, this approach offers a comprehensive pathway to reduce emissions while maintaining efficient and reliable offshore hydrocarbon extraction (Akintobi *et al.*, 2022; Adeniji *et al.*, 2022).

2.4 Implementation Considerations

The implementation of emission monitoring and optimization frameworks in floating oil and gas production systems involves multiple complex considerations that extend beyond technology deployment as shown in figure 3. Successful adoption depends on seamless system integration, robust cybersecurity and data integrity measures, and comprehensive operator training supported by effective decision support tools. Addressing these factors is essential to ensure reliable performance, regulatory compliance, and operational efficiency.

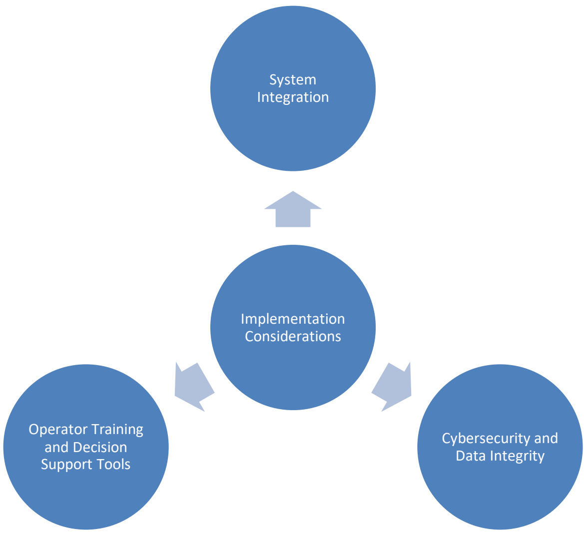

Figure 3: Implementation Considerations

System integration is a fundamental challenge when implementing emission monitoring solutions in floating production systems. These platforms typically rely on distributed control systems (DCS) and supervisory control and data acquisition (SCADA) systems to manage and automate complex operations. The emission monitoring framework must be closely linked with these onboard control systems to provide real-time, synchronized data flows and enable integrated decision-making. DCS platforms coordinate the control of processes such as power generation, gas compression, and water injection, while SCADA systems provide higher-level supervisory control and remote monitoring capabilities. Integration allows emission data collected from sensors and analyzers to be fed directly into the control logic, enabling automated adjustments to operational parameters that optimize emissions and energy consumption (Sobowale *et al.*, 2022; Akintobi *et al.*, 2022). Moreover, integration facilitates automated alerting and shutdown sequences in the event of abnormal emissions or equipment faults, enhancing safety and environmental protection. Achieving seamless interoperability requires adherence to industry communication standards, such as OPC UA and Modbus, and often necessitates custom middleware solutions to bridge legacy systems with modern emission monitoring technology.

In parallel with integration, cybersecurity and data integrity are critical implementation considerations in offshore environments, where connectivity and system complexity pose vulnerabilities. Floating production systems are increasingly connected to shore-based control centers and cloud platforms for data analytics and regulatory reporting, exposing them to potential cyber threats. Unauthorized access or cyberattacks could lead to data manipulation, operational disruption, or safety incidents, undermining both environmental and business objectives. To mitigate these risks, emission monitoring systems must be designed with cybersecurity by design principles, incorporating multi-layered defenses such as firewalls, intrusion detection systems, encryption, and secure authentication protocols. Additionally, maintaining data integrity ensures that emission records are accurate, tamper-proof, and compliant with regulatory audit requirements. Blockchain technology and secure log management systems are emerging as promising solutions to guarantee immutable and verifiable data trails. Regular cybersecurity assessments and incident response planning are also essential components to maintain system resilience over the lifetime of the platform (Adewoyin, 2022; Onukwulu *et al.*, 2022).

Another pivotal aspect of implementation is operator training and the deployment of decision support tools to translate complex emission data into actionable insights. Floating production systems operate in dynamic and often harsh offshore environments, requiring operators to make rapid decisions balancing safety, production targets, and environmental compliance. Training programs must therefore equip personnel with the knowledge to interpret emission metrics, understand system interdependencies, and respond effectively to anomalies or optimization opportunities (Clarke *et al.*, 2020; Srivastava *et al.*, 2020; Patterson *et al.*, 2021). Simulation-based training modules, incorporating digital twins of the production system, can provide hands-on experience in managing emission control scenarios without risking actual operations. Decision support tools powered by artificial intelligence and machine learning can augment operator capabilities by analyzing vast amounts of data, identifying patterns, and recommending optimized operational adjustments. These tools can highlight trade-offs between production efficiency and emission reduction, enabling informed decision-making aligned with regulatory requirements and corporate sustainability goals. Visualization dashboards with intuitive interfaces further enhance situational awareness and facilitate communication among multidisciplinary teams.

The implementation of emission monitoring and optimization frameworks in floating oil and gas production systems demands a holistic approach that integrates technological, cybersecurity, and human factors. Linking monitoring systems with onboard DCS and SCADA platforms enables real-time data-driven control and enhances operational responsiveness. Robust cybersecurity and data integrity safeguards protect against evolving cyber threats and ensure reliable compliance reporting. Comprehensive operator training, supported by advanced decision support tools, empowers personnel to effectively manage emissions while optimizing production performance. Addressing these considerations is essential to unlocking the full potential of emission monitoring technologies and advancing sustainable offshore oil and gas operations in a rapidly changing regulatory and environmental landscape (Ogunnowo *et al.*, 2022; Okolo *et al.*, 2022).

2.5 Future Work

As the offshore oil and gas industry strives to meet increasingly stringent environmental regulations and reduce its carbon footprint, future advancements in emission monitoring and optimization will be pivotal. Building upon current frameworks, several promising research directions and technological innovations are poised to transform emission management in floating production systems (Bento and Fontes, 2019; Nilsson *et al.*, 2021). Key among these are the integration with carbon capture and storage (CCS) technologies, enhanced monitoring using satellite and drone-based platforms, and the development of autonomous optimization systems.

Carbon capture and storage represents a critical technology for achieving deep decarbonization in energy-intensive industries, including offshore oil and gas production. CCS involves capturing CO_2 emissions at the source, transporting the captured gas, and securely storing it underground or utilizing it in enhanced oil recovery or other industrial processes. Future work should focus on integrating CCS seamlessly with floating production systems, creating a closed-loop approach where emissions are not only monitored but also actively mitigated.

This integration poses several technical challenges and research opportunities. First, the framework must be extended to include real-time monitoring of capture system efficiency, CO_2 purity, and leak detection within the CCS infrastructure (Adu *et al.*, 2019; Singh *et al.*, 2020). Process models and digital twins should be adapted to simulate the coupled dynamics of production and capture units, enabling optimization algorithms to balance capture rates with operational constraints and energy consumption. Furthermore, the logistics of offshore CO_2 transport—whether via subsea pipelines or ship-based transfer—require robust scheduling and risk management tools integrated within the emission optimization framework. Addressing these aspects will enable floating production systems to transition from solely emission monitoring toward proactive carbon management.

While onboard sensor networks provide granular and real-time data on emissions, they are often limited to fixed locations and may not detect diffuse or fugitive emissions effectively. Future research should explore augmenting local monitoring with satellite and drone-based remote sensing technologies to achieve comprehensive spatial coverage and improved detection capabilities.

Satellites equipped with spectrometers and infrared sensors can monitor large offshore areas for plumes of methane and other greenhouse gases. Recent advances in satellite resolution and data processing enable near-real-time tracking of emission sources, helping to identify leaks or flaring events that might be missed by onboard systems. Complementing satellites, unmanned aerial vehicles (UAVs) or drones offer high-resolution, flexible inspection capabilities. Drones can be deployed for targeted surveys around critical infrastructure, quickly mapping emission hotspots and verifying sensor data.

Integrating satellite and drone data into the emission monitoring architecture requires developing advanced data fusion and validation algorithms capable of reconciling disparate data sources and scales. Additionally, autonomous flight planning and operation for drones must be developed to ensure safe and effective monitoring in offshore environments. Such integrated remote sensing strategies will provide operators with a comprehensive, multi-tiered view of emissions, enabling faster response and more informed optimization decisions.

The future of emission management lies in fully autonomous optimization systems that can operate with minimal human intervention, dynamically adjusting production parameters to optimize emission performance in real time. Building on advances in artificial intelligence (AI), machine learning (ML), and digital twins, autonomous systems will combine predictive modeling, decision-making algorithms, and real-time data to implement optimal control strategies continuously.

These systems will leverage reinforcement learning and adaptive control techniques to learn from operational data and improve their policies over time. By autonomously balancing competing objectives—such as minimizing emissions, maximizing production, and ensuring equipment safety—autonomous controllers can respond instantly to changing conditions, process disturbances, or equipment faults (Gamer *et al.*, 2020; Rubio *et al.*, 2021; Tofangchi *et al*, 2021). Furthermore, integration with automated maintenance scheduling and fault detection systems will enable proactive mitigation of emission sources before they escalate.

To achieve practical deployment, future work must address challenges related to system reliability, cybersecurity, and operator trust. Human-machine interfaces should be designed to provide transparency and explainability of autonomous decisions, facilitating operator oversight and collaboration. Testing and validation under diverse offshore scenarios will be essential to ensure safety and robustness.

Future work in emission monitoring and optimization for floating oil and gas production systems will focus on integrating CCS technologies for active carbon management, enhancing emission detection through satellite and drone-based remote sensing, and developing autonomous optimization systems that enable real-time, adaptive control. Together, these advances promise to significantly reduce the environmental impact of offshore hydrocarbon production while maintaining operational efficiency and safety, driving the industry toward a more sustainable future (Sommer *et al.*, 2019; Vora *et al.*, 2021; Sircar *et al.*, 2021).

Conclusion

This presents a comprehensive framework for emission monitoring and optimization in energy-intensive floating oil and gas production systems. The framework integrates advanced sensor technologies capable of real-time detection of key greenhouse gases and pollutants with robust data acquisition, fusion, and validation methods tailored for harsh offshore environments. It further incorporates detailed thermodynamic and equipment performance models, combined with multi-objective optimization algorithms and artificial intelligence, to balance emission reduction goals with production efficiency. Operational strategies such as load shedding, fuel switching, scheduling, and flare minimization complement the framework, enabling practical and dynamic emission management.

The contributions of this work lie in its holistic approach, combining state-of-the-art sensor infrastructure, digital twins, and AI-driven optimization within an integrated system. This enables floating production operators to gain unprecedented visibility into emissions and proactively optimize operations, thus addressing the long-standing challenges of monitoring and controlling emissions in complex offshore environments. The framework's adaptability to incorporate future advancements such as carbon capture integration and remote sensing further enhances its potential impact.

From a regulatory perspective, this framework supports compliance with increasingly stringent emission standards by providing accurate, continuous emissions data and actionable insights. It empowers operators to demonstrate environmental accountability while minimizing the risk of costly penalties or shutdowns. Operationally, the optimization capabilities contribute to reduced energy consumption and improved system reliability, translating to lower operational costs and enhanced safety.

Looking ahead, the vision is for smarter, low-emission offshore production systems where autonomous optimization, real-time emission monitoring, and integrated carbon management become standard practice. Such systems will leverage digital twins, AI, and emerging technologies like satellite and drone monitoring to create resilient, efficient, and environmentally responsible offshore assets. Ultimately, this evolution will enable the oil and gas industry to reconcile its operational demands with global sustainability goals, fostering a cleaner and more sustainable future for offshore energy production.

References

1. Achumie, G.O., Oyegbade, I.K., Igwe, A.N., Ofodile, O.C. and Azubuike, C., 2022. A Conceptual Model for Reducing Occupational Exposure Risks in High-Risk Manufacturing and Petrochemical Industries through Industrial Hygiene Practices.
2. Adedokun, A.P., Adeoye, O., Eleluwor, E., Oke, M.O., Ibiyomi, C., Okenwa, O., Ubendu, O.N. and Obi, I., 2022, August. Production Restoration Following Long Term Community Crisis–A Case Study of Well X in ABC Field, Onshore Nigeria. In SPE Nigeria Annual International Conference and Exhibition (p. D031S016R001). SPE.
3. Adeniji, I.E., Kokogho, E., Olorunfemi, T.A., Nwaozomudoh, M.O., Odio, P.E. and Sobowale, A., 2022. Customized financial solutions: Conceptualizing increased market share among Nigerian small and medium enterprises. International Journal of Social Science Exceptional Research, 1(1), pp.128-140.
4. Adesemoye, O.E., Chukwuma-Eke, E.C., Lawal, C.I., Isibor, N.J., Akintobi, A.O. and Ezeh, F.S., (2021). Improving financial forecasting accuracy through advanced data visualization techniques. IRE Journals. 2021; 4 (10): 275-277 [online]
5. Adewoyin, M.A., 2021. Developing frameworks for managing low-carbon energy transitions: overcoming barriers to implementation in the oil and gas industry.

6. Adewoyin, M.A., 2022. Advances in risk-based inspection technologies: Mitigating asset integrity challenges in aging oil and gas infrastructure.
7. ADEWOYIN, M.A., OGUNNOWO, E.O., FIEMOTONGHA, J.E., IGUNMA, T.O. and ADELEKE, A.K., 2020. A Conceptual Framework for Dynamic Mechanical Analysis in High-Performance Material Selection.
8. ADEWOYIN, M.A., OGUNNOWO, E.O., FIEMOTONGHA, J.E., IGUNMA, T.O. and ADELEKE, A.K., 2020. Advances in Thermofluid Simulation for Heat Transfer Optimization in Compact Mechanical Devices.
9. ADEWOYIN, M.A., OGUNNOWO, E.O., FIEMOTONGHA, J.E., IGUNMA, T.O. and ADELEKE, A.K., 2021. Advances in CFD-Driven Design for Fluid-Particle Separation and Filtration Systems in Engineering Applications.
10. Adu, E., Zhang, Y. and Liu, D., 2019. Current situation of carbon dioxide capture, storage, and enhanced oil recovery in the oil and gas industry. The Canadian Journal of Chemical Engineering, 97(5), pp.1048-1076.
11. Ajiga David (2021). Strategic Framework for Leveraging Artificial Intelligence to Improve Financial Reporting Accuracy and Restore Public Trust. International Journal of Multidisciplinary Research and Growth Evaluation. 2(1), pp 882-892
12. Ajiga, D., Ayanponle, L. and Okatta, C.G., 2022. AI-powered HR analytics: Transforming workforce optimization and decision-making. International Journal of Science and Research Archive, 5(2), pp.338-346.
13. Akintobi, A.O., Okeke, I.C. and Ajani, O.B., 2022. Advancing economic growth through enhanced tax compliance and revenue generation: Leveraging data analytics and strategic policy reforms. International Journal of Frontline Research in Multidisciplinary Studies, 1(2), pp.085-093.
14. Akintobi, A.O., Okeke, I.C. and Ajani, O.B., 2022. Transformative tax policy reforms to attract foreign direct investment: Building sustainable economic frameworks in emerging economies. Int J Multidiscip Res Updates, 4(1), pp.8-15.
15. Akpan, U.U., Adekoya, K.O., Awe, E.T., Garba, N., Oguncoker, G.D. and Ojo, S.G., 2017. Mini-STRs screening of 12 relatives of Hausa origin in northern Nigeria. Nigerian Journal of Basic and Applied Sciences, 25(1), pp.48-57.
16. Akpan, U.U., Awe, T.E. and Idowu, D., 2019. Types and frequency of fingerprint minutiae in individuals of Igbo and Yoruba ethnic groups of Nigeria. Ruhuna Journal of Science, 10(1).
17. Asadi, J., Yazdani, E., Dehaghani, Y.H. and Kazempoor, P., 2021. Technical evaluation and optimization of a flare gas recovery system for improving energy efficiency and reducing emissions. Energy conversion and management, 236, p.114076.
18. Awe, E.T. and Akpan, U.U., 2017. Cytological study of Allium cepa and Allium sativum.
19. Awe, E.T., 2017. Hybridization of snout mouth deformed and normal mouth African catfish Clarias gariepinus. Animal Research International, 14(3), pp.2804-2808.
20. Awe, E.T., Akpan, U.U. and Adekoya, K.O., 2017. Evaluation of two MiniSTR loci mutation events in five Father-Mother-Child trios of Yoruba origin. Nigerian Journal of Biotechnology, 33, pp.120-124.

21. Awe, T., 2021. Cellular Localization Of Iron-Handling Proteins Required For Magnetic Orientation In C. Elegans.
22. Bento, N. and Fontes, M., 2019. Emergence of floating offshore wind energy: Technology and industry. Renewable and Sustainable Energy Reviews, 99, pp.66-82.
23. Chudi, O., Iwegbu, J., Tetegan, G., Ikwueze, O., Effiom, O., Oke-Oghene, U., Ayodeji, B., Opatewa, S., Oladipo, T., Afolayan, T. and Tonyi, A.A., 2019, August. Integration of rock physics and seismic inversion for net-to-gross estimation: Implication for reservoir modelling and field development in offshore Niger Delta. In SPE Nigeria Annual International Conference and Exhibition (p. D033S028R010). SPE.
24. Chudi, O., Kanu, M., Anaevune, A., Yamusa, I., Iwegbu, J., Sesan, O. and Musa, J., 2019, August. A Novel Approach for Predicting Sand Stringers: A Case Study of the Baka Field Offshore Nigeria. In SPE Nigeria Annual International Conference and Exhibition (p. D023S006R003). SPE.
25. Chudi, O., Kanu, M., Johnbosco, U., Udoh, N., Fatunmbi, A., Onwuka, O., Ebimobowei, W., Ovwigho, I., Tichelaar, B. and Xian, H., 2021. Application of Quantitative Interpretation in De-risking Hydrocarbon Type: Implication for Shallow Water Exploration in EKEM Field, Niger Delta.
26. Clarke, L., Sahin-Dikmen, M. and Winch, C., 2020. Overcoming diverse approaches to vocational education and training to combat climate change: The case of low energy construction in Europe. Oxford Review of Education, 46(5), pp.619-636.
27. Daraojimba, A.I., Ubamadu, B.C., Ojika, F.U., Owobu, O., Abieba, O.A. and Esan, O.J., 2021. Optimizing AI models for crossfunctional collaboration: A framework for improving product roadmap execution in agile teams. IRE Journals, 5(1), p.14.
28. Dienagha, I.N., Onyeke, F.O., Digitemie, W.N. and Adekunle, M., 2021. Strategic reviews of greenfield gas projects in Africa: Lessons learned for expanding regional energy infrastructure and security.
29. Elete, T.Y., Nwulu, E.O., Omomo, K.O., Esiri, A.E. and Aderamo, A.T., 2022. Data analytics as a catalyst for operational optimization: A comprehensive review of techniques in the oil and gas sector. International Journal of Frontline Research in Multidisciplinary Studies, 1(2), pp.32-45.
30. Elete, T.Y., Nwulu, E.O., Omomo, K.O., Esiri, A.E. and Aderamo, A.T., 2022. A generic framework for ensuring safety and efficiency in international engineering projects: key concepts and strategic approaches. International Journal of Frontline Research and Reviews, 1(2), pp.23-26.
31. Esan, O.J., Uzozie, O.T. and Onaghinor, O., 2022. Policy and Operational Synergies: Strategic Supply Chain Optimization for National Economic Growth.
32. Gamer, T., Hoernicke, M., Kloepper, B., Bauer, R. and Isaksson, A.J., 2020. The autonomous industrial plant–future of process engineering, operations and maintenance. Journal of Process Control, 88, pp.101-110.
33. Giuliani, M., Camarda, G., Montini, M., Cadei, L., Bianco, A., Shokry, A., Baraldi, P. and Zio, E., 2019, March. Flaring events prediction and prevention through advanced big data analytics and machine learning algorithms. In Offshore Mediterranean Conference and Exhibition (pp. OMC-2019). OMC.
34. Komi, L.S., Chianumba, E.C., Forkuo, A.Y., Osamika, D. and Mustapha, A.Y., 2022. A conceptual framework for training community health workers through virtual public health education modules. IRE Journals, 5(11), pp.332-335.

35. Magnus, K., Edwin, Q., Samuel, O. and Nedomien, O., 2011, September. Onshore 4D processing: Niger Delta example: Kolo Creek case study. In SEG International Exposition and Annual Meeting (pp. SEG-2011). SEG.
36. Mustapha, A.Y., Chianumba, E.C., Forkuo, A.Y., Osamika, D. and Komi, L.S., 2021. Systematic Review of Digital Maternal Health Education Interventions in Low-Infrastructure Environments. International Journal of Multidisciplinary Research and Growth Evaluation, 2(1), pp.909-918.
37. Nilsson, L.J., Bauer, F., Åhman, M., Andersson, F.N., Bataille, C., de la Rue du Can, S., Ericsson, K., Hansen, T., Johansson, B., Lechtenböhmer, S. and van Sluisveld, M., 2021. An industrial policy framework for transforming energy and emissions intensive industries towards zero emissions. Climate Policy, 21(8), pp.1053-1065.
38. Nwulu, E.O., Elete, T.Y., Aderamo, A.T., Esiri, A.E. and Omomo, K.O., 2022. Predicting industry advancements: A comprehensive outlook on future trends and innovations in oil and gas engineering. International Journal of Frontline Research in Engineering and Technology, 1(2), pp.6-18.
39. Nwulu, E.O., Elete, T.Y., Aderamo, A.T., Esiri, A.E. and Omomo, K.O., 2022. Predicting industry advancements: A comprehensive outlook on future trends and innovations in oil and gas engineering. International Journal of Frontline Research in Engineering and Technology, 1(2), pp.6-18.
40. Nwulu, E.O., Elete, T.Y., Erhueh, O.V., Akano, O.A. and Aderamo, A.T., 2022. Integrative project and asset management strategies to maximize gas production: A review of best practices. World Journal of Advanced Science and Technology, 2(2), pp.18-33.
41. Nwulu, E.O., Elete, T.Y., Erhueh, O.V., Akano, O.A. and Omomo, K.O., 2022. Leadership in multidisciplinary engineering projects: A review of effective management practices and outcomes. International Journal of Scientific Research Updates, 4(2), pp.188-197.
42. Odio, P.E., Kokogho, E., Olorunfemi, T.A., Nwaozomudoh, M.O., Adeniji, I.E. and Sobowale, A., 2021. Innovative financial solutions: A conceptual framework for expanding SME portfolios in Nigeria's banking sector. International Journal of Multidisciplinary Research and Growth Evaluation, 2(1), pp.495-507.
43. Ogunnowo, E., Ogu, E., Egbumokei, P., Dienagha, I. and Digitemie, W., 2021. Theoretical framework for dynamic mechanical analysis in material selection for highperformance engineering applications. Open Access Research Journal of Multidisciplinary Studies, 1(2), pp.117-131.
44. Ogunnowo, E., Ogu, E., Egbumokei, P., Dienagha, I. and Digitemie, W., 2022. Theoretical model for predicting microstructural evolution in superalloys under directed energy deposition (DED) processes. Magna Scientia Advanced Research and Reviews, 5(1), pp.76-89.
45. OGUNNOWO, E.O., ADEWOYIN, M.A., FIEMOTONGHA, J.E., IGUNMA, T.O. and ADELEKE, A.K., 2020. Systematic Review of Non-Destructive Testing Methods for Predictive Failure Analysis in Mechanical Systems.
46. OGUNNOWO, E.O., ADEWOYIN, M.A., FIEMOTONGHA, J.E., IGUNMA, T.O. and ADELEKE, A.K., 2021. A Conceptual Model for Simulation-Based Optimization of HVAC Systems Using Heat Flow Analytics.

47. Ogunwole, O., Onukwulu, E.C., Sam-Bulya, N.J., Joel, M.O. and Achumie, G.O., 2022. Optimizing automated pipelines for realtime data processing in digital media and e-commerce. International Journal of Multidisciplinary Research and Growth Evaluation, 3(1), pp.112-120.
48. Ogunwole, O., Onukwulu, E.C., Sam-Bulya, N.J., Joel, M.O. and Ewim, C.P., 2022. Enhancing risk management in big data systems: A framework for secure and scalable investments. International Journal of Multidisciplinary Comprehensive Research, 1(1), pp.10-16.
49. Ojika, F.U., Owobu, O., Abieba, O.A., Esan, O.J., Daraojimba, A.I. and Ubamadu, B.C., 2021. A conceptual framework for AI-driven digital transformation: Leveraging NLP and machine learning for enhanced data flow in retail operations. IRE Journals, 4(9).
50. Ojika, F.U., Owobu, W.O., Abieba, O.A., Esan, O.J., Ubamadu, B.C. and Daraojimba, A.I., 2022. The Impact of Machine Learning on Image Processing: A Conceptual Model for Real-Time Retail Data Analysis and Model Optimization.
51. Ojika, F.U., Owobu, W.O., Abieba, O.A., Esan, O.J., Ubamadu, B.C. and Daraojimba, A.I., 2022. Integrating TensorFlow with Cloud-Based Solutions: A Scalable Model for Real-Time Decision-Making in AI-Powered Retail Systems.
52. Okolo, F.C., Etukudoh, E.A., Ogunwole, O., Osho, G.O. and Basiru, J.O., 2022. Advances in Integrated Geographic Information Systems and AI Surveillance for Real-Time Transportation Threat Monitoring. Journal name missing.
53. Okolo, F.C., Etukudoh, E.A., Ogunwole, O., Osho, G.O. and Basiru, J.O., 2022. Policy-Oriented Framework for Multi-Agency Data Integration Across National Transportation and Infrastructure Systems. Journal name missing.
54. Okolo, F.C., Etukudoh, E.A., Ogunwole, O.L.U.F.U.N.M.I.L.A.Y.O., Osho, G.O. and Basiru, J.O., 2021. Systematic Review of Cyber Threats and Resilience Strategies Across Global Supply Chains and Transportation Networks. Journal name missing.
55. Omisola, J.O., Etukudoh, E.A., Okenwa, O.K. and Tokunbo, G.I., 2020. Innovating Project Delivery and Piping Design for Sustainability in the Oil and Gas Industry: A Conceptual Framework. perception, 24, pp.28-35.
56. Onaghinor, O., Uzozie, O.T. and Esan, O.J., 2022. Optimizing Project Management in Multinational Supply Chains: A Framework for Data-Driven Decision-Making and Performance Tracking.
57. Onaghinor, O., Uzozie, O.T., Esan, O.J., Etukudoh, E.A. and Omisola, J.O., 2021. Predictive modeling in procurement: A framework for using spend analytics and forecasting to optimize inventory control. IRE Journals, 5(6), pp.312-314.
58. Onukwulu, E.C., Fiemotongha, J.E., Igwe, A.N. and Ewim, C.P.M., 2022. International Journal of Management and Organizational Research.
59. Onyeke, F.O., Odujobi, O., Adikwu, F.E. and Elete, T.Y., 2022. Advancements in the integration and optimization of control systems: Overcoming challenges in DCS, SIS, and PLC deployments for refinery automation. Open Access Res J Multidiscip Stud, 4(2), pp.94-101.
60. Onyeke, F.O., Odujobi, O., Adikwu, F.E. and Elete, T.Y., 2022. Innovative approaches to enhancing functional safety in Distributed Control Systems (DCS) and Safety Instrumented Systems (SIS) for oil and

gas applications. Open Access Research Journal of Multidisciplinary Studies, 3 (1). Open Access Research Journal of Multidisciplinary Studies, 3(1), pp.106-112.

61. Orieno Omamode Henry Oluchukwu Modesta Oluoha, Abisola Odeshina, Oluwatosin Reis, Friday Okpeke, Verlinda Attipoe (2021). Project Management Innovations for Strengthening Cybersecurity Compliance across Complex Enterprises. 2(1), pp 871 – 881.
62. Oyedokun, O.O., 2019. Green human resource management practices and its effect on the sustainable competitive edge in the Nigerian manufacturing industry (Dangote) (Doctoral dissertation, Dublin Business School).
63. Patterson, D., Gonzalez, J., Le, Q., Liang, C., Munguia, L.M., Rothchild, D., So, D., Texier, M. and Dean, J., 2021. Carbon emissions and large neural network training. arXiv preprint arXiv:2104.10350.
64. Rubio, F., Llopis-Albert, C. and Valero, F., 2021. Multi-objective optimization of costs and energy efficiency associated with autonomous industrial processes for sustainable growth. Technological Forecasting and Social Change, 173, p.121115.
65. Singh, M., Senthilkumar, S., Rajput, S. and Neogi, S., 2020. Pore-functionalized and hydrolytically robust Cd (II)-metal–organic framework for highly selective, multicyclic CO2 adsorption and fast-responsive luminescent monitoring of Fe (III) and Cr (VI) ions with notable sensitivity and reusability. Inorganic chemistry, 59(5), pp.3012-3025.
66. Sircar, A., Yadav, K., Rayavarapu, K., Bist, N. and Oza, H., 2021. Application of machine learning and artificial intelligence in oil and gas industry. Petroleum Research, 6(4), pp.379-391.
67. Sobowale, A., Odio, P.E., Kokogho, E., Olorunfemi, T.A., Nwaozomudoh, M.O. and Adeniji, I.E., 2022. A conceptual model for reducing operational delays in currency distribution across Nigerian banks. International Journal of Social Science Exceptional Research, 1(6), pp.17-29.
68. Solanke*, B., Aigbokhai, U., Kanu, M. and Madiba, G., 2014. Impact of accounting for velocity anisotropy on depth image; Niger Delta case history. In SEG Technical Program Expanded Abstracts 2014 (pp. 400-404). Society of Exploration Geophysicists.
69. Sommer, B., Fowler, A.M., Macreadie, P.I., Palandro, D.A., Aziz, A.C. and Booth, D.J., 2019. Decommissioning of offshore oil and gas structures–Environmental opportunities and challenges. Science of the total environment, 658, pp.973-981.
70. Srivastava, R., Awojobi, M.O.H.A.M.M.E.D. and Amann, J., 2020. Training the Workforce for High-Performance Buildings: Enhancing Skills for Operations and Maintenance. American Council for an Energy-Efficient Economy, Washington, DC.
71. Tofangchi, S., Hanelt, A., Marz, D. and Kolbe, L.M., 2021. Handling the efficiency–personalization trade-off in service robotics: A machine-learning approach. Journal of Management Information Systems, 38(1), pp.246-276.
72. Ubamadu, B.C., Bihani, D., Daraojimba, A.I., Osho, G.O., Omisola, J.O. and Etukudoh, E.A., 2022. Optimizing Smart Contract Development: A Practical Model for Gasless Transactions via Facial Recognition in Blockchain.
73. Uzozie, O.T., Onaghinor, O. and Esan, O.J., 2022. Innovating Last-Mile Delivery Post-Pandemic: A Dual-Continent Framework for Leveraging Robotics and AI.

74. Uzozie, O.T., Onaghinor, O., Esan, O.J., Osho, G.O. and Olatunde, J., 2022. Global Supply Chain Strategy: Framework for Managing Cross-Continental Efficiency and Performance in Multinational Operations.
75. Vora, M., Sanni, S. and Flage, R., 2021. An environmental risk assessment framework for enhanced oil recovery solutions from offshore oil and gas industry. Environmental impact assessment review, 88, p.106512.