UNIVERSITY OF PIRAEUS
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EMERGING TECHNOLOGIES IN THE OIL AND GAS INDUSTRY: OPPORTUNITIES AND CHALLENGES

Dissertation

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Abstract

This thesis explores the central and transformative role of emerging technologies in the global oil and gas industry. It focuses on how modern innovations such as artificial intelligence (AI), blockchain, digital twins, robotics, and the Internet of Things (IoT) are changing the way the industry operates at every stage, from upstream exploration and drilling to downstream transportation, management, and safety monitoring. These technologies are improving efficiency by reducing human error, cutting costs, speeding up processes, and allowing companies to make faster and more informed decisions based on real-time data. They are also helping the sector respond to increasing expectations related to environmental protection, emissions reduction, and workplace safety.

However, the adoption of these technologies does not happen smoothly or equally across all regions. This thesis examines the main barriers that slow down or complicate technological change, including technical limitations, high financial costs, lack of trained personnel, cybersecurity threats, and regulatory or legal obstacles. To better understand how these challenges differ or overlap across the world, the research looks at three case studies from three different continents: the United States in North America, Scotland in the United Kingdom in Europe, and Nigeria in Africa.

These locations were chosen because they each represent different economic conditions, regulatory systems, and levels of technological development. The United States is one of the largest and most technologically advanced oil and gas producers, with strong private investment and digital infrastructure. Scotland, as part of the UK's North Sea oil industry, faces both innovation pressure and regulatory constraints linked to sustainability, energy transition, and offshore operations. Nigeria, on the other hand, is a major oil producer in Africa but often struggles with infrastructure gaps, security issues, and governance challenges, which affect how emerging technologies can be applied.

By comparing these three cases, the study highlights both the differences and the shared experiences in adopting new technologies. The research shows how national policies, economic priorities, workforce skills, and environmental expectations influence the speed and success of

technological change. After analyzing the case studies, the thesis identifies the most persistent and widespread challenge that appears across all three countries and explains why it remains difficult to solve despite growing awareness and investment.

The aim of the study is to provide a detailed and balanced understanding of how emerging technologies are shaping the oil and gas sector today and what their adoption might mean for the future of the industry. It seeks to show both the opportunities created by innovation and the obstacles that must be addressed to ensure responsible, efficient, and sustainable development moving forward.

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Contents

Chapter 1
Introduction

1.1 Preamble

The oil and gas industry remains central to the global energy system, supplying the majority of the world's energy needs. At the same time, the sector faces mounting pressure to adapt to volatile market conditions, increasingly strict environmental regulations, and the urgent demand for greater efficiency and safety. These challenges are unfolding against the backdrop of digital transformation, which is reshaping even the most traditional industries. Oil and gas, long known for its conservative culture, is now at a turning point where innovation is no longer optional but essential for long-term sustainability and competitiveness.

This thesis examines the role of emerging technologies in the oil and gas sector, with particular attention to artificial intelligence (AI), blockchain, robotics, big data analytics, and the Internet of Things (IoT). The central research question is what opportunities and challenges do emerging technologies present for the oil and gas industry.

Even though new technologies have a lot of potential, they often face many challenges before being widely adopted. While people understand the possible benefits, the actual use of these technologies is often slowed down by rules, costs, and how organizations work. Studying these factors is important because it can help students, policymakers, and professionals make better decisions, encourage innovation, and build more sustainable and competitive systems in the future.

The core problem addressed is the uneven and often slow adoption of transformative technologies in a traditionally risk-averse sector. Many digital tools have demonstrated the potential to transform exploration, production, and distribution processes, yet barriers remain. High implementation costs, regulatory uncertainty, cybersecurity concerns, and organizational inertia all contribute to the gap between technological potential and actual adoption.

To frame this analysis, the Technology Acceptance Model (TAM) is applied, offering insights into how organizations adopt new tools in complex, capital-intensive settings. This framework helps explain the often mixed attitudes of managers, engineers, and field operators toward digital technologies.

Two hypotheses guide the research. The first hypothesis is that the integration of emerging technologies significantly improves operational efficiency in the oil and gas industry. The second one describes that regulatory, financial, and organizational barriers are the main impediments to widespread adoption.

The study contributes to ongoing debates on digital transformation, sustainability, and innovation within one of the world's most critical sectors. It aims to provide insights relevant both to academic research and industry practice, supporting the adaptation of the oil and gas industry to

1.2 Research Questions

The study is guided by three research questions, which are: what are the most significant emerging technologies in the oil and gas sector, what benefits do these technologies offer and what challenges hinder their adoption.

1.3 Structure of the thesis

This thesis is organized into five chapters to provide a comprehensive analysis of emerging technologies in the oil and gas industry.

Chapter 1, the introduction presents the research topic, the background, highlights the research problem, and outlines the objectives and research questions. It also provides an overview of the thesis structure. The next chapter, the literature review, analyses the existing studies on emerging technologies in the oil and gas sector, including AI, blockchain, IoT, robotics, digital twins, CCUS, and hydrogen. It identifies research gaps and challenges in technology adoption. Chapter 3, the research methodology, explains the research design, data collection methods, and approach for analyzing case studies from the US, Scotland, and Nigeria. It also discusses the criteria for selecting these cases. The case study analysis, chapter 4, presents the findings from the three case studies, comparing how emerging technologies are applied in the locations chosen, the benefits, and the challenges faced in each country. And lastly, in chapter 5, the discussion and the conclusion synthesize the findings, identify common trends and issues, discusses implications for the oil and gas industry, presents the scope and the limitations of this paper and finally, provides recommendations for future research.

Chapter 2
Literature Review

2.1 Overview of the Oil and Gas Industry

This chapter looks at how the oil and gas sector developed, why it remains so important today, and how emerging technologies are transforming the way it operates. Technologies like artificial intelligence, blockchain, robotics, big data, and 3D printing are helping companies work smarter, safer, and more sustainably. At the same time, they raise new questions about cost, training, and long-term adaptation.

The goal of this chapter is to explore how these innovations are changing the industry, what opportunities they create, what challenges they bring, and how companies are putting them into practice. By understanding both the progress and the obstacles, we can get a clearer picture of where the oil and gas industry stands today and where it might be heading in the future.

2.1.1 History and evolution

The commercial oil era began in 1859, when the first oil well was drilled in Titusville, Pennsylvania. Since then, the industry has served as a cornerstone of global economic growth, powering industrial development and modern life. Early expansion was driven by rising demand for kerosene, gasoline, and lubricants, supported by pioneering companies such as Standard Oil, Shell, and BP, which advanced drilling, refining, and transportation technologies.

A pivotal shift occurred in the 1970s with the growing influence of the Organization of the Petroleum Exporting Countries (OPEC). By exerting control over production and prices, OPEC altered the dynamics of global energy markets, triggering oil crises that reshaped international energy policies.

Today, oil and gas continue to supply more than half of the world's energy. Yet, the sector faces growing challenges, including price volatility, geopolitical tension, and the pressing global shift toward low-carbon energy. As climate targets and decarbonization strategies accelerate, the industry is compelled to integrate cleaner technologies and sustainable practices. (Zand, 2024)

2.2 Current Trends and Economic Significance

Despite the global shift toward renewable energy, oil and gas remain economically significant. Price fluctuations, political conflicts, and cyclical demand continue to shape investment decisions. At the same time, environmental concerns such as greenhouse gas emissions, water usage, and ecosystem impacts are driving the industry to adopt more sustainable practices. According to Research and Markets (2025), the global oil and gas market was valued at USD 6.7 trillion in 2023, with projections of USD 6.9 trillion in 2024 and USD 8.9 trillion by 2031. This reflects a compound annual growth rate (CAGR) of 3.68% between 2024 and 2031. Growth is supported by sustained demand, despite strong pressure from decarbonization initiatives.

The industry is divided into three key sectors: the upstream operations, which aim the exploration and production of oil and gas and it involves locating and extracting oil and gas reserves; the midstream operations which handle crude oil and natural gas transportation and storage and the downstream operations, which are responsible for refining crude oil into usable products like gasoline, diesel, and natural gas.

2.3 Emerging Technologies

According to many researchers and also as a logical statement, Halaweh (2013) affirms that the oil and gas industry has always been closely linked with technological innovation, constantly adopting new tools to improve efficiency, safety, and sustainability. In recent years, the sector has undergone rapid transformation, especially through the integration of digital technologies. Today, oil and gas companies rely on complex networks for sourcing, trading, and transporting resources, supported by tools like cloud computing, automation, big data, artificial intelligence (AI), and machine learning. These technologies help optimize operations and improve decision-making across the supply chain.

One of the most significant impacts of these innovations has been seen in North America, where advances in oil and gas technologies have reshaped the energy landscape. To remain competitive, companies must keep up with these fast-evolving tools. This ongoing digital transformation is not limited to production, it extends across all business areas, from logistics and safety to environmental monitoring and predictive maintenance.

Emerging technologies, those still developing or just beginning to be adopted, play a key role in this shift. Although there is no single definition, emerging technologies are generally seen as innovations that are expected to grow in importance over the next five to ten years. These tools are not yet fully mainstream, but they hold strong potential to disrupt current practices and improve performance. As they continue to evolve, emerging technologies will shape the future of the oil and gas industry and influence how we live, work, and interact in broader society.

As Duggal (2023) states, for all types of technologies created, there are certain general characteristics, such as novelty, which translates to how far from an already existing technology the new technology is; uncertainty, because one could never know beforehand how sure the use of this technology will be in the future, potential for disruption, which shows how much potential would a new technology have to completely cease or temporarily disrupt and replace an existing market or a work method; interdisciplinarity, how flexible would a technology be to be used in various other domains, other industries and by other types of employees, from engineers to teachers or researchers and the last characteristic, the pace of change, how fast or slow a technology is changing and how easy or hard it is to keep up with it in all the domains affected by its usage.

As seen above, starting to explore emerging technologies is essential, as they drive the creation of more innovative tools, systems, and solutions that can ease the processes and avoid putting workers in different situations of danger. One of the main users or new technology has always been the military, by frequently adopting such advancements to strengthen strategic capabilities and maintain a technological edge and another wide range of industries, like healthcare, finance, education, manufacturing, and transportation, also rely on new technologies to transform their operations, improve outcomes, and stay ahead in a competitive landscape.

The technologies that will be discussed are: blockchain, AI and machine learning, virtual reality and augmented reality for digital twinning, robotics and automation, Internet of Things (IoT), big data analytics and additive manufacturing.

Blockchain technology streamlines and secures the complex processes involved in the oil and gas supply chain, while significantly enhancing and promoting transparency. Tasks such as trading, inventory management, shipment tracking, and financial transactions become more efficient and easier to oversee. By recording every transaction, from component orders to delivery routes, on decentralized, encrypted ledgers, blockchain establishes a reliable and tamper-proof source of truth. Each entry is timestamped and assigned to the respective employee, ensuring permanent and verifiable records that support regulatory compliance. This unified system fosters clearer communication and coordination among all stakeholders. Additionally, blockchain boosts accountability and helps prevent supply chain disruptions through features like decentralized payments, cross-chain interoperability, and smart contracts tailored to the oil and gas sector (Dennis,2024). Figure 1 shows visually the diagram of a blockchain in the oil and gas industry. A related technology used in a blockchain are smart contracts. Smart contracts are self-executing digital agreements written in code, where the terms of the agreement are directly embedded within the program itself.

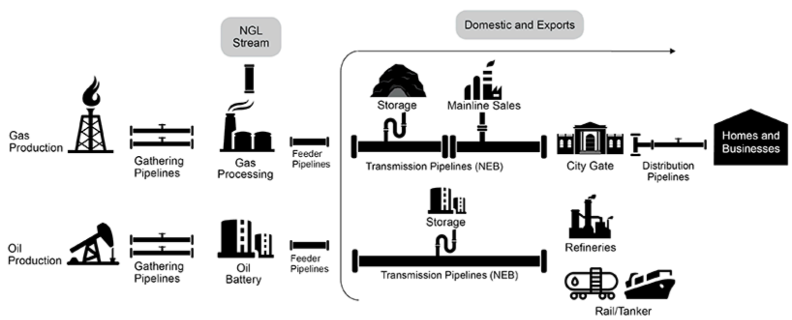

Figure 1. Diagram of a blockchain in the oil and gas industry

They automatically carry out actions when predefined conditions are met, without the need for intermediaries like lawyers, brokers, or notaries. They automate and enforce contractual agreements. In the oil and gas sector, they can streamline transactions, reduce administrative costs, and ensure timely payments. (AZTech Training & Consultancy, 2024)

According to Prestidge (2022), Artificial Intelligence (AI) is playing a transformative role in the oil and gas industry, particularly in exploration, production, and asset management. It enhances seismic data analysis, leading to more accurate identification of reservoirs and reducing the environmental impact by improving the management of emissions and leak detection. AI also automates drilling operations, optimizes energy consumption, and supports real-time reservoir monitoring.

By combining predictive analytics with IoT sensors, AI enables continuous surveillance of drilling rigs and pipelines. These technologies help identify anomalies and risks early, improving operational safety and reducing unplanned downtime. For instance, AI-powered algorithms process seismic and geological data to build more accurate reservoir models, while digital twins, virtual replicas of physical assets, simulate performance and optimize operational efficiency.

In predictive maintenance, AI analyses data from equipment sensors to detect patterns and anticipate failures before they happen. This proactive approach helps minimize maintenance costs, avoid catastrophic breakdowns, and improve worker safety.

Reservoir Management: AI analyses complex geological data to pinpoint high-potential drilling locations, enabling more efficient extraction and reduced operational costs.

Data Analytics: Advanced AI-driven analytics tools process large datasets from multiple sources, delivering actionable insights that improve production planning, resource allocation, and overall decision-making.

Virtual Reality (VR) immerses users in a fully digital environment, distinguishing it from Augmented Reality (AR), which simply overlays digital elements onto the real world, as shown in figure 2.

Figure 2. Simplified examples of virtual reality, augmented reality and mixed reality

VR is particularly valuable for applications such as training, simulation, visualization, equipment inspections, and remote support. Like AR, VR is gaining traction among enterprise-level organizations. In the oil and gas industry, the adoption of immersive technologies can reduce operational costs by up to 25% per barrel. These technologies, along with Mixed Reality (MR), help with training and simulation on-site, help integrate physical and digital environments to boost efficiency, improve accuracy, minimize human error and increase the efficiency of disaster management. MR, much like digital twin systems, enables real-time interaction between virtual models and physical systems, making it especially useful for industries dealing with complex machinery and field operations.

Sircar (2022) states that digital twinning is a consequence of the use of VR data. VR can be used to create a Digital Twin of an entire plant and its equipment, a virtual replica that simulates 1 to 1 the facility's real-world operations. Digital Twins offer plenty of advantages, allowing engineers to test systems in a risk-free virtual environment, free from concerns about actual equipment failure. They enable simulation of operational issues, helping streamline troubleshooting and decision-making. For instance, an equipment engineer can remotely examine a malfunctioning component through a VR-based Digital Twin and provide repair recommendations. Additionally, before construction begins, a Digital Twin can assess the feasibility of plant layouts and equipment designs, identifying potential improvements and optimizations.

In the robotics sector, engineers are supporting the idea to use advanced technologies to automate tasks and address complex subsurface challenges in the oil and gas sector. Innovations in robotics and automation are transforming operations by reducing costs while enhancing safety, efficiency, and speed. One of the most widely implemented solutions is Robotic Process Automation (RPA) (UiPath Inc.,2025), which streamlines repetitive, rule-based tasks such as data entry, document handling, and reporting. For instance, during the decommissioning of oil and gas wells, RPA significantly accelerates the process and reduces the risk of human error. Meanwhile, robotic systems are increasingly deployed for critical operations like pipeline inspection, maintenance, and repair, allowing work to be performed in hazardous environments with minimal human involvement. These robots are engineered to withstand extreme temperatures, harsh weather, and other demanding conditions typically encountered in the oil, gas, and petrochemical industries.

The Internet of Things (IoT) refers to a network of interconnected smart devices that communicate and exchange data with one another. This technology has ushered in a new era of seamless connectivity, enabling machines and systems to interact in real time to create more efficient, productive, and responsive environments. In the oil and gas sector, IoT facilitates real-time monitoring and data collection across various operations in the supply chain, leading to improved management, enhanced field communication, reduced equipment downtime, increased workers' safety and helped with pipeline monitoring. Nowadays, companies are adopting IoT-enabled devices to monitor critical infrastructure such as pumps, pipelines, and filters, helping to detect and prevent costly leaks before they occur. Industrial IoT (IIoT) also supports cost reduction by optimizing resource use and maintenance scheduling. Today, compact smart sensors play a crucial role in maintaining safe and efficient production by continuously collecting data on parameters like temperature, pressure, and gas concentrations. (IBM,2023)

Data analytics has become a powerful tool in the technological toolkit, transforming how industries operate, especially in data-intensive fields like oil and gas. With massive volumes of data generated daily from exploration, drilling, and production activities, the sector is increasingly turning to big data and advanced analytics to drive smarter decision-making. Data scientists can uncover meaningful patterns and trends by analysing historical and real-time data from various sources. The oil and gas industry, which has been collecting data for decades, is well-positioned to leverage these insights.

By applying analytics, companies can identify optimal drilling sites, monitor equipment performance, and predict maintenance needs. Predictive analytics, such as variable analysis and condition-based monitoring, enable scenario modelling and early detection of potential failures. This proactive approach helps prevent costly downtime by ensuring maintenance is carried out before equipment fails. Real-time analytics further empower decision-makers with actionable insights, prevention of cyber-attacks is increased, thus leading to more efficient operations, cost savings, and enhanced productivity. As a result, big data and analytics are now central to achieving operational excellence across the oil and gas value chain. (Brancaccio, 2020)

The last type of technology is additive manufacturing. As Kumar et al. (2021) states in one of his articles, it is commonly known as 3D printing and is revolutionizing operations in the oil and gas sector by offering faster production, localized manufacturing, and cost-effective component repairs. Utilizing technologies like powder bed fusion (PBF), where a 3D printing process uses a laser or electron beam to fuse layers of powdered metal or plastic into solid parts. It's known for producing strong, high-precision components, often used with metals like titanium; stereolithography (SLA), where a UV laser is used to harden liquid resin layer by layer. SLA creates highly detailed and smooth-surfaced parts, often used for prototyping and complex designs; and fused deposition modeling (FDM), where thermoplastic filament is melted and deposited layer by layer to build an object. It's widely used for functional parts and prototypes. This approach enables the fabrication of complex parts from advanced materials such as titanium alloys and high-performance polymers like PEEK. By producing components directly on-site or near the point of use, companies can significantly cut lead times, customize tooling and spare parts, they can easily try new prototypes and test them, reduce reliance on global supply chains, and limit unplanned equipment downtime. Beyond operational gains, additive manufacturing contributes to environmental sustainability by minimizing raw material waste and reducing greenhouse gas emissions, ultimately allowing oil and gas firms to operate more efficiently with smaller inventories and a lighter ecological footprint.

2.4 Opportunities

The energy sector is increasingly turning to innovative technologies to improve productivity, optimize operations, and support better decision-making. Companies of all sizes are investing heavily in developing and applying tools such as data analytics, automation and machine learning to gain a competitive edge.

Some key places where, if applied, these technologies increased the opportunities of development are: predictive maintenance for heavy machinery and infrastructure, smart optimization of operational performance across the value chain that promotes transparency and disaster management and risk-free operations management.

In recent years, oil and gas companies have focused on building the right digital foundations to effectively use innovative technologies. Now, the priority is shifting from small-scale success stories to achieving company-wide transformation. Scaling up these technologies, however, is not straightforward. Many organizations still struggle with challenges such as outdated systems, lack of integration across departments, and the need for continuous improvement of digital tools. One particular issue is "model drift", where the performance of predictive technologies weakens over time due to poor data quality or a lack of ongoing system updates. To fully realize the potential of innovative technologies, companies must commit to both maintaining and improving their digital infrastructure.

To further increase the usage and the success of these innovations, companies, users, employees can take some initiatives. These initiatives are discussed in the section below.

The first initiative is about leadership commitment and being open to the vision. For any large-scale transformation to succeed, strong leadership support is essential. Leaders must understand the value of digital technologies and be willing to invest resources, both financial and human, into their development. Just as important, they must consistently communicate this vision throughout the organization and encourage collaboration across departments, exactly like a transparent blockchain.

Leadership also plays a crucial role in breaking down internal barriers. As emerging technologies often require access to data from various parts of the business, cooperation is key. Leaders can foster a culture where experimentation is welcomed and risk-taking is seen as a path to growth, particularly in high-stakes areas like drilling and reservoir management.

Secondly, companies need to get started with scaling innovation. To begin, companies need a clear vision of how digital tools can create value. This involves assessing current capabilities, identifying gaps, and deciding where external help might accelerate progress. Success depends on close collaboration across departments, from engineering to procurement, and a strategy that balances internal development with external partnerships.

The oil and gas sectors are moving quickly to adopt innovative technologies as a way to improve operations and stay competitive in a rapidly changing world. While the early focus was on laying digital foundations, the current challenge lies in scaling these technologies across the enterprise. Success depends on leadership support, a commitment to continuous improvement, and a culture that embraces change.

Further and lastly, companies need to ensure the above-mentioned scaling of the 3 P’s: the people, the processes, and the platforms. Scaling digital tools isn't as simple as adding more computing power. It requires scaling up everything, from the workforce and data pipelines to systems and governance structures. Companies need to ensure their teams are trained, their data is reliable, and their systems are robust enough to handle increasing complexity.

Innovative technologies must be regularly tested, refined, and aligned with changing business needs. This requires coordination between IT teams, operations, and decision-makers. Additionally, businesses must decide whether to develop certain capabilities in-house or partner with external providers, a decision that impacts strategy, costs, and intellectual property.

2.5 Challenges

Perhaps the biggest barrier to scaling technology is resistance to change. Employees accustomed to traditional methods may be hesitant to trust or use new tools. Therefore, companies must invest in change management, educating employees about the benefits of innovation, helping them to upskill and reskill in certain cases, by showing how their roles will evolve, and involving them in the process practically.

This cultural shift is critical. People need to see innovative tools as part of their daily work, not just a side project from the IT department. Feedback from users is essential to improving digital tools over time.

The challenges can be various and different from environment to environment. With global shifts toward clean energy, companies need to focus increasingly on reducing carbon emissions and investing in low-carbon technologies.

Another reason for backing up is money. The need to adopt digital tools such as AI, cloud computing, and automation for operational efficiency is rising. Companies face challenges in scaling these technologies while maintaining profitability, also meeting with the ongoing question of “is it or will it be worth it long-term?”.

At the same time, some governments worldwide are tightening regulations on methane emissions and other pollutants. This forces companies to innovate while staying compliant, thing that might be contradictory sometimes, because while reinitiating the employees into the new technologies, companies still need to produce, consume and make profit. While investing, either in the actual technologies or in the reskilling processes, point mentioned earlier, companies may feel that their efforts are not appreciated, if the public authorities become stricter and stricter.

2.6 Practical uses

As for the practical use of these technologies, each one of them brings out increased productivity, efficiency or reduces the risks associated with manual labour in remote parts of the installations. From the research of StartUs Insights, the practical uses of these technologies are varied and intertwined, as it can be seen further.

2.6.1 Practical use of additive manufacturing

It can be used to make custom tools and spare parts, designed to meet specific needs. With 3D printing, these parts can be produced on demand, helping reduce downtime and the need to keep a large stock.

3D printing also lets engineers make trials, prototypes before producing the final product, in order to test multiple entries for a certain equipment, such as valves or heat exchangers, and thus they accelerate the stages of repairment and good functioning.

In remote locations that are very hard to reach and also very hard to transport spare parts or entire equipment, like offshore oil platforms, 3D printing can be used directly on site in order to produce critical parts that are damaged or missing, either for turbines or drilling equipment and thus cutting short the time of creation and delivery to the remote location of those specific parts.

2.6.2 Practical Uses of Artificial Intelligence

By reducing dependency on geological investigation for exploration, AI analyzes large datasets for geoscientists to identify new drilling locations. AI also increases the well productivity and reduces exploration risks by forecasting potential failures.

AI algorithms simulate and manage complex subsurface reservoirs, optimizing oil and gas recovery and extending the operational life of fields. AI-driven models predict reservoir behavior, optimize production rates, manage reservoir pressure, and improve recovery techniques.

AI analyzes sensor data from equipment such as pumps, compressors, and turbines to predetermine potential breakdowns, so that the workers avoid unexpected failures and reduce repair costs.

2.6.3 Practical Uses of Augmented Reality (AR) & Virtual Reality (VR)

AR headsets give technicians hands-free access to essential information such as schematics, sensor data, and maintenance guidelines. This enables real-time troubleshooting and remote support, reducing mistakes and boosting efficiency during inspections and repairs. VR, on the other hand, immerses workers in simulated environments, such as virtual oil rigs or refineries, so they can safely train for hazardous situations.

With the help of AR and VR, digital twins can be created. These are digital copies of something real, like an oil rig or refinery. It’s made using data from sensors. Engineers can use it to watch how things work, test ideas, and see what might happen before it does.

Also, with VR, companies can create virtual emergencies, like spills or explosions. Workers can then practice how to react, but without any real danger.

When combined with digital twins and 3D models, AR and VR also support advanced planning and predictive maintenance. AR and VR let workers practice in realistic virtual environments, as they can go through dangerous situations like gas leaks or broken equipment safely, which helps them remember what to do in real life.

2.6.4 Practical Uses of Big Data & Analytics in Oil & Gas

Equipment Management: With IoT sensors on rigs and pipelines, data like temperature, pressure, and vibration is collected all the time. Big data and machine learning study this information to spot problems early, so maintenance can be done before equipment breaks down.

Cybersecurity and Risk Management: Big data checks network activity, finds unusual behavior, and warns about possible cyberattacks. Together with AI and blockchain, it helps stop threats in real time, makes transactions safer, and keeps supply chains more secure.

Drilling Process: Using old drilling data and real-time sensor information, advanced analytics creates models to guide drilling. This helps adjust drilling settings, avoid dangerous issues, and reduce risks like blowouts.

2.6.5 Practical Uses of Blockchain

Blockchain helps oil and gas companies cut costs, increase accountability, and improve their supply chains. It works like a secure digital record book that cannot be changed, which reduces mistakes and fraud. Smart contracts (automatic digital agreements) speed up payments and remove middlemen. Big players like BP and Shell already use it for better transparency and smoother trade. Some examples are: sensor-enabled invoicing, through which payments are triggered automatically by IoT sensors that measure production or chemical use, avoiding billing mistakes; smart contracts, where contracts run automatically and securely without needing third parties and commodity trading, through which all trading partners see the same data at the same time, reducing errors and fraud.

2.6.6 Practical Uses of CleanTech

Clean technologies help reduce the oil and gas industry's environmental impact. This includes capturing carbon, using hydrogen, lowering methane emissions, and adding renewable energy to operations. Examples: carbon capture, where CO_2 emissions are trapped and stored instead of being released; renewable energy, through which oilfields combine solar, wind, and diesel to lower costs and emissions; and finally, water management, where water is recycled from fracking reduces waste and freshwater use.

2.6.7 Practical Uses of Cloud Computing

Oil and gas operations generate massive amounts of data. Cloud computing offers flexible, secure, and cheaper storage compared to traditional on-site servers. It makes data accessible in real time and supports better decision-making.

Cloud computing can be used in remote monitoring, where operators track equipment from anywhere using IoT devices and cloud dashboards; centralized storage, where data from multiple sites is stored together for better analysis and collaboration; and in disaster recovery, where cloud backups protect data and allow quick recovery after accidents or cyberattacks.

2.6.8 Practical Uses of Connectivity Technologies

Strong internet connections (fiber optics, 4G, 5G, satellite, microwave) make oil and gas operations safer, faster, and more automated, especially in remote areas.

Connectivity technologies can be used in a variety of ways, including in the optimization of production, with real-time monitoring that improves efficiency and reduces waste; smart maintenance, where sensors detect problems before breakdowns happen; and in drilling automation, where data is sent instantly to control centers, speeding up drilling and reducing human error.

2.6.9 Practical Uses of Internet of Things (IoT)

IoT means using smart sensors and devices to connect equipment, workers, and supply chains. This improves safety, efficiency, and decision-making.

Some examples where IoT is used are: in the supply chain, where it tracks equipment and deliveries to save costs; in pipeline monitoring, where sensors detect leaks and pressure changes to prevent accidents and last, but not least, a very important usage is for the workers' safety: where wearables (helmets, vests, boots) track vital signs and warn about dangers.

2.6.10 Practical Uses of Advanced Robotics

Robots reduce risk and improve efficiency by taking over dangerous, repetitive, or complex tasks. They're used underwater, in refineries, and for environmental monitoring, like in subsea exploration, through underwater robots that inspect deep-sea rigs and pipelines; in environmental monitoring, with drones that measure pollution and track environmental changes; and finally in the maintenance of pipelines, where pipeline robots, where these kind of robots travel inside pipelines to detect leaks and weak points.

2.7 Startups

According to StartUs Insights (2025), there are various startups worth paying attention to, in all the types of technologies. For additive manufacturing, there is Additive Adoption, a UAE-based company offering 3D printing solutions using desktop metal products for all scales of production, from complex prototypes to on-demand tooling. Their agile additive manufacturing technology helps shorten the design cycle for critical oil and gas components, enabling fast prototyping, multiple design iterations, and quick testing of concepts. The company's solutions support the rapid creation of jigs, fixtures, prototypes, and tooling, while also providing advantages such as bridge tooling, low-volume production, and improved supply chain management.

UK startup Veunex built an AI assistant to make oil and gas work safer. It helps health and safety teams check risks, share updates, and give training in real time. The system works on both land and offshore rigs, turning raw data into useful insights that speed up risk management and improve safety at sites like refineries and drilling platforms.

India's Simbott creates AR and VR training tools for oil and gas workers. Using digital twins, it lets teams practice site planning, monitoring, and even welding in a safe virtual space. Their AR Welding System mixes real actions with digital feedback, while the VR Welding Simulator teaches techniques like GMAW and SMAW. They also offer training for drilling, equipment use, and safety rules.

Serbia’s DeepsinAI made the Deep Platform, which uses AI to improve oil and gas operations. It connects with existing systems to manage wells, cut costs, and boost performance. Special tools track greenhouse gas emissions, check wells automatically, and predict future oil flow. This helps companies make smarter decisions and work more efficiently.

Based in Saint Vincent and the Grenadines, Fund Token DAO uses crypto to raise money for green energy projects. People who hold their token can vote on which projects, like carbon capture, renewables, or net-zero oil and gas, get funded. The system runs on blockchain, which makes transactions transparent, secure, and eco-focused.

US startup Clean Refineries created a new way to process hydrocarbons that produces fuel like gasoline and aviation fuel without releasing greenhouse gases. Their closed-loop system is safer, cheaper, and better for the environment. The technology is modular, so it can be scaled to different sites and work with many types of feedstocks.

US-based Plutoshift AI runs a cloud platform called Gravity that gathers data from sensors and systems in oil and gas sites. It turns this data into reports, alerts, and predictions so companies can fix issues before they cause downtime. By keeping everything in one place, the platform makes operations smoother and helps teams save time and resources.

Bulgaria’s LLcloud tracks abandoned oil and gas wells to measure methane and other emissions. It uses drones, satellites, and other sensors to gather data, which is then shown in easy-to-read maps and reports. The platform helps environmental groups and regulators check well conditions more accurately and at larger scales.

Spain’s FOSSA provides satellite-based communication for oil and gas companies. Its nanosatellites let teams monitor pipelines, equipment, and offshore assets in real time, even in very remote areas. The system is energy-efficient and works with existing monitoring tech to give reliable data around the globe.

Turkey's AIS Field builds robots to inspect and clean oil and gas equipment. Their robots check tanks, boilers, and underwater structures for corrosion and thickness without putting people at risk. They also provide software that organizes inspection data and allows real-time tracking, making maintenance faster and safer.

2.7.1 Outlook for the Oil & Gas Industry

This part of the chapter looks at how these startups are driving innovation and shaping the future of oil and gas. It also explores some of the main trends happening around the world, like where most of the new technologies are being developed, how many patents are being filed, and what kind of research is being done on topics like shale gas. Altogether, these changes show how the industry is slowly moving toward a more digital and sustainable future, with both large corporations and new innovators working side by side.

2.7.1.1 Patents & Grants

According to the research of Antriksh(2023) , the oil and gas industry is advancing technologically, with over 196000 patents filed and 12700+ grants awarded. These numbers show the industry's ongoing innovation in improving exploration, production, and sustainability.

2.7.1.2 Global Footprint

Technological advancements are concentrated in regions including the US, India, UK, Canada, and Germany. There are also hubs in cities like Houston, Dubai, Mumbai, Calgary, and London. These centres drive the adoption and implementation of new technologies, reflecting the industry's global transformation and growth.

Also according to StartUs Insights (2025), the big data market in the oil and gas sector is estimated to increase by USD 22.42 billion, at a CAGR of 27.17% between 2023 and 2028. This is due to fluctuating oil prices, stringent environmental regulations, and the need for optimized operations across upstream midstream, and downstream activities. Big data and analytics enable real-time monitoring of drilling operations, predictive maintenance of equipment, and seismic data analysis for accurate exploration. By integrating data from multiple sources such as sensors and IoT devices, it enables companies to reduce operational costs, minimize environmental risks, and maximize production efficiency.

As seen, the oil and gas industry is undergoing major changes driven by technology and data. In addition to broad technological progress, shale gas has once again become a hot topic in the energy world. After several years of slower activity, interest in shale gas is rising as countries look for more secure and cleaner energy options compared to coal and traditional oil. Advances in drilling, hydraulic fracturing, and data-driven exploration have reopened discussions about its potential, making shale gas a key subject in both industry research and investment today. From advanced methods in shale gas exploration, like improved well logging, spectroscopy, and data integration to the growing use of big data and AI, these innovations are reshaping how energy is discovered and produced.

2.7.1.3 Advanced techniques for determining parameters of interest in the shale gas exploration

As several students and professors from the Oil and Gas University in Ploiesti, Romania, such as Frunzescu, Branoiu and students Georgescu and Lungu (2019) analysed, scientists and engineers are able to use advanced methods to better understand shale gas reservoirs and decide if they are worth developing. Shale gas is trapped deep underground in layers of rock, so it is harder to study than conventional gas. To overcome this, researchers rely on a mix of laboratory tests, well-logging tools, and modern software.

2.7.1.4 Main Parameters

Several rock properties are especially important for shale gas exploration, such as: the thermal maturity shows if the rock has been heated enough over time to produce hydrocarbons; the thickness of the shale layer, as thicker layers usually mean more gas potential; the total organic content (TOC) indicates how much organic matter is present to generate gas; the porosity and permeability measure how much space is available in the rock and how easily fluids can move through it; and gas storage types, where gas can be attached to surfaces inside pores or free gas that is able to move more easily through fractures.

2.7.1.5 Techniques Used

Frunzescu(2019) also explained different tools and methods to measure these properties, and they are: core analysis, as physical samples from drilling are tested in labs for maturity and organic content; well logs, where tools are lowered into boreholes measure rock thickness, porosity, and clay content; elemental capture spectroscopy (ECS) identifies the elements in the rock to estimate its composition; SpectroLith breaks down the mineral content into parts like clay, quartz, and carbonates; and ELAN software combines all these data sources to estimate porosity, gas saturation, and other parameters in a more complete model.

By combining all these measurements, geologists can get a clearer picture of how much gas is in the rock and how easy it will be to extract, like estimating adsorbed vs. free gas helps companies know whether gas will flow naturally or need more stimulation; understanding permeability and fractures helps plan hydraulic fracturing (fracking) and knowing the organic richness and maturity avoids wasting money drilling in areas with little potential.

Frunzescu(2019) also mentioned that these techniques are especially useful when planning horizontal drilling and fracking operations. Since shale gas is usually spread out in thin layers, these modern methods allow companies to choose the best drilling paths, reduce risks, and improve efficiency.

Overall, the research shows that advanced tools like spectroscopy, detailed well logging, and data-integration software are changing the way shale gas exploration is done. Instead of guessing or starting measurements with flawed data, companies can now rely on precise data to evaluate reservoirs, reduce uncertainty, and improve the chances of successful gas extraction.

Chapter 3
Methodology

3.1 Research Design

This research uses a mixed-methods approach, qualitative and quantitative, because the focus is on understanding ideas, experiences, and differences between countries, after having analysed raw numerical data. A case study method is used, looking at three countries, the USA and Nigeria. This makes it possible to compare how technology is accepted in three different contexts: two highly developed and one developing. Along with this, a literature analysis is included, so existing knowledge from books, articles, and reports can guide the study.

3.2 Data Collection

The study is based on secondary data, taken from reliable sources such as academic journals and books that explain the Technology Acceptance Model (TAM), from industry reports that show how technology is used in energy, specifically in the oil and gas industry and from expert interviews or comments already published in reports or articles.

Secondary data is chosen because it is more available and trustworthy, already polished, so it allows a clear comparison between countries.

3.3 Data Analysis

The data will be studied using thematic analysis. This means reading through the material and finding usage of technology, trust in technology, access to infrastructure, cultural attitudes, and government policies. After identifying the main themes, a comparative case study approach will be used. This means comparing the USA, Scotland and Nigeria side by side to see where they are similar and where they are different in terms of technology acceptance. This approach helps to highlight how culture, economics, and policy affect technology use.

3.4 Ethical Considerations

The research follows academic integrity rules. All sources will be cited properly to avoid plagiarism. Since the data is secondary, there are no risks to participants. If expert opinions are included from published sources, they will be referenced correctly and respected. The research is carried out in a transparent way, using only trustworthy sources.

Chapter 4
Findings and Discussion

4.1 Case Studies of Technology Adoption

Before looking at how technology is adopted in different countries, it's important to understand the main theory that guides this analysis, the Technology Acceptance Model (TAM) developed by Davis in 1989. This model helps explain why people choose to use or reject new technologies. It focuses on two main ideas: perceived usefulness, meaning how helpful someone thinks a technology will be for their work, and perceived ease of use, meaning how simple it is to learn and operate. Together, these factors shape whether people accept or resist a new system.

In this chapter, the TAM framework is used to compare how technology is adopted in three very different contexts, the United States, Scotland (UK), and Nigeria. These countries were chosen because they represent diverse economic, cultural, and technological environments. The U.S. reflects a highly developed and resource-rich setting with advanced digital systems; Scotland stands as a traditional oil and gas hub that is slowly transitioning toward modern solutions; and Nigeria represents an emerging market where technology has great potential but also faces major infrastructural and educational barriers.

By using TAM to study these three cases, we can better understand how different factors, such as culture, leadership, organizational support, and worker perception, influence the acceptance and use of new technologies in the oil and gas industry. This comparison helps reveal both the global patterns and the local differences in how technology adoption happens in practice.

4.1.1. Theoretical Framework - Technology Acceptance Model (TAM)

The chosen case studies are the United States, Scotland(UK) and Nigeria. To complete the analysis, the Technology Acceptance Model (TAM)(Davis, 1989) is used. The choice of these three countries was not aleatory: they represent three very different contexts, from three different continents, that highlight how cultural, economic, and infrastructural factors influence technology adoption. The U.S., as one of the world's largest and most technologically advanced economies, offers a setting where digital infrastructure, education, and innovation ecosystems are highly developed, allowing us to observe TAM in a mature, resource-rich environment. UK, represented by Scotland, a hub of oil and gas exploration, can be seen balancing towards the adoption of more and more technologies from the upstream to the downstream activities, and Nigeria, at the end of the spectrum, is one of Africa's fastest-growing economies with a rapidly expanding digital market but faces challenges such as limited infrastructure, affordability, and varying digital literacy. By comparing these two countries, we can better understand how perceived usefulness and ease of use shape technology acceptance in both advanced and emerging markets, providing insights into global patterns of adoption.

4.1.2 Case 1: The US

According to Salazar et al. (2021), the oil and gas industry in the United States is built on technology. Without horizontal drilling, hydraulic fracturing, advanced seismic imaging, robotics, or automated monitoring, the industry simply could not operate at the scale it does today. But even though new tools can make companies more competitive and even boost the value of their assets by a quarter, not every company is quick to adopt them. Some organizations move aggressively, while others remain reticent, cautious. This uneven pace of adoption is what motivated the authors of this paper: they wanted to understand what actually pushes or holds back oil and gas firms when it comes to embracing new technology.

To get at this, the researchers focused on a few key ideas that have been studied in other industries but rarely tested in oil and gas. One of them is "absorptive capacity," which is basically how good a company is at spotting new knowledge, understanding it, and putting it to use. Another is "top management support," meaning whether executives show real commitment to adoption. A third is "resource commitment," or the willingness to put money, staff, and time into the effort. The authors also looked at "organizational support," the broader culture and structures that encourage people inside the firm to champion new ideas. Finally, they examined "task–technology fit," which is a fancy way of asking: does this new technology actually make people's jobs easier or more effective or is it just a façade?

The team surveyed 172 people across the US oil and gas industry, including upstream drillers, downstream refiners, pipeline companies, and service providers. Respondents held a variety of roles, most of them technical or operational, with a mix of companies ranging from medium sized firms to those with billions in revenue. Using their survey responses, the researchers built statistical models to test which of these factors really drive adoption in practice.

The results are both intuitive and surprising. The biggest surprise is that having the ability to absorb new knowledge by itself does not lead to adoption. In other words, it is not enough for a company to be smart or informed about new technologies. What really matters is whether that knowledge turns into broader organizational support. If the culture is right and people across the company are drawn to be engaged, then resources follow. The link between organizational support and resource commitment was strong, showing that culture drives the willingness to spend money and allocate staff.

Another clear finding is that task–technology fit is crucial. If employees on the ground believe a new technology genuinely helps them perform their tasks better, adoption is far more likely. This was one of the strongest effects in the entire model and it comes from making the employees try the technologies themselves. This reinforces the idea that adoption cannot simply be pushed from the top down. No matter how enthusiastic executives are, if the people who actually use the technology do not see its value, the project will stall.

The study also shows that widespread organizational support has a direct effect on adoption, even beyond resources. This suggests that adoption is as much a social and cultural process as it is a technical or financial one. Praising eager workers inside the company, peer encouragement, and a general climate of openness to innovation matter just as much as money and technical readiness. Top management support is still important, but what really makes adoption stick is when the whole organization, not just the executives, gets behind the change.

For managers and decision makers, spotting new technologies and building awareness is only the first step. Companies need to create structures and practices that encourage effective communication across teams and departments. They need to listen carefully to the people who will actually use the tools, making sure the new technology really fits their daily tasks. And when there is enthusiasm and support, leaders need to back it up with concrete resources: budgets, staff, time, and equipment.

The larger takeaway is that adopting technology in oil and gas is not just a technical or financial decision. It is people's decision. Companies that succeed are the ones that combine knowledge, culture, leadership, and practical usefulness, like when teams rally behind a change, when managers unlock the necessary resources, and when the technology itself clearly makes work better, then adoption happens. Without all these aligning, even the most promising innovations may struggle to take root.

This study, while focused on the US, has lessons that apply more broadly. It highlights the human side of technology adoption in a sector often thought of as purely engineering-driven. It also points to areas for further research, such as whether these patterns are applicable in other regions of the world or in different energy sectors like renewables. What is certain is that in an industry facing price volatility, environmental pressures, and the constant need to stay competitive, the ability to adopt technology effectively will remain one of the most important capabilities a company can build.

4.1.3 Case 2: Nigeria

According to Bolodeoku et al. (2022), oil and gas workers in Nigeria are aware of the usefulness of technology and how that perception affects their performance at work. The basic idea is that when workers think a technology is helpful, it can influence things like their job satisfaction, their productivity, how much support they feel from the organization, and their overall commitment. The study is important because the oil and gas industry is one of the biggest drivers of Nigeria's economy, but it also faces problems like high turnover, skills shortages, and constant pressure to improve efficiency with extensive manual labor.

The authors begin by explaining why technology matters in oil and gas. The sector has moved far beyond basic drilling to advanced tools like artificial intelligence, robotics, seismic imaging, and virtual reality. These technologies can improve safety and productivity, but they are also complicated to teach on one side, to learn on the other side, and sometimes intimidating for workers. For technology adoption to succeed, employees must believe that the tools are genuinely useful. This is based on the Technology Acceptance Model, which says that people's willingness to use a system depends mainly on two things: how easy it is to use, and how useful they think it is. The paper focuses on the second factor, perceived usefulness.

The study used a survey of 495 oil and gas employees in Nigeria, with 460 valid responses collected. The questionnaire asked about workers' experiences with technology and their perceptions of whether these tools truly made their jobs easier or more effective. The authors used statistical methods called structural equation modelling to analyse the responses and test the relationship between perceived usefulness and different outcomes. The key outcomes they looked at were employee satisfaction, employee commitment, employee productivity, and organizational support.

The demographic breakdown shows that most respondents were male, between 21 and 50 years old, with solid educational backgrounds. Many of them worked in drilling, maintenance, or operations, which are core functions in oil and gas. This matters because these are exactly the kinds of jobs where technology adoption is most visible and desired, through robotics, digital platforms, and advanced drilling equipment that directly affect how these workers carry out their daily tasks.

The results showed that perceived usefulness of technology had a clear positive effect on employee satisfaction, productivity, and organizational support. Workers who believed the technology they used was valuable reported being more satisfied with their jobs, more productive, and more confident that their company supported them. Interestingly, the weakest link was with employee commitment. Even if workers found the technology useful, this did not strongly increase their loyalty or commitment to the company. In other words, they might feel more satisfied or productive, but that doesn't necessarily make them want to stay in the organization long term, with other factors like wellbeing, salaries being as equal or even more important for them.

One key finding is that satisfaction was the most affected factor. Workers who saw technology as useful were more likely to feel good about their jobs. Productivity was next, showing that useful technology helps people work faster and better, which creates also the short-term satisfaction that makes you want to be even more productive throughout the day. Organizational support also improved, because when technology works well, employees tend to feel that their company is investing in them. But commitment lagged behind, suggesting that other factors, like pay, recognition, or workplace culture, may be even more important for keeping employees loyal.

The authors link their findings to the broader context of Nigeria's oil and gas sector. The industry has been hit hard by economic challenges, COVID-19 disruptions, and structural issues such as corruption, policy instability, and lack of training, through institutions such as nationally and internationally certified training centers that offer qualification and re-qualification courses. In such an environment, just providing technology is not enough. Workers need training and proper communication to see how the tools help their daily roles. Without this, new systems can create stress rather than motivation and the study stresses that training and organizational support are critical to making technology adoption successful.

The discussion highlights that while perceived usefulness clearly matters, it is not an automatic thing to happen. Workers' commitment requires more than just technology, it needs a supportive environment, fair compensation, and strong leadership. The findings suggest that managers should not only introduce new technology but also show employees why it matters, how it benefits them, and give them the training to feel confident using it. This way, technology adoption can lead to higher satisfaction and productivity and possibly reduce turnover.

In conclusion, the study proves that technology can strongly affect employee performance, but mostly through satisfaction, productivity, and organizational support. The weakest effect was on commitment, showing that loyalty to the organization cannot be built by adopting technology alone. The authors recommend that oil and gas companies in Nigeria focus more on training programs, requalifying courses, transparent communication, and strategies that emphasize both the usefulness and ease of use of technology. They also suggest that compensation and working conditions should be improved alongside technological innovation, so that workers see technology as part of a broader effort to support them.

4.1.4 Case 3: Scotland (The UK)

If the U.S. case showed us that adoption depends largely on organizational structures such as management support, resource commitment, and whether a technology fits the actual tasks, and if the Nigerian case highlighted the workers' perspective, where believing a technology is useful improves job satisfaction and productivity but does not do much for long-term loyalty, then the Scottish case brings in a third angle: the psychology of the decision makers.

As analyzed in the paper of Roberts et al. (2021), that focused on the North Sea oil and gas sector in Scotland, which is a very mature but at the same time, also a conservative industry. The authors wanted to understand why new technologies, even when they promise big benefits, often face delays or resistance at the early stages of adoption. Their main claim is that the decision to adopt is not just about technical feasibility or return on investment, but also about how individual managers, engineers, and leaders perceive risk, how motivated they feel to push change, and how their organizational culture treats innovation.

The researchers approached the question by studying case examples and interviews with people in oil and gas companies who act as "gatekeepers" for new technology. These are the people who decide whether to give a vendor a meeting, whether to allow a pilot project, or whether to sponsor a trial. They also surveyed workers to get a sense of the overall innovation climate in organizations. Unlike the U.S. study, which relied on statistical modeling, and the Nigerian study, which measured perceived usefulness with surveys, the Scottish study used qualitative methods to capture the thought processes and psychological factors influencing decisions.

Their results grouped the psychological influences into six main families. The first is personality, such as openness to novelty or risk aversion. In a high-risk industry like offshore oil and gas, strong risk aversion often leads people to prefer the status quo rather than testing something unproven. The second is motivation, meaning what decision makers feel they stand to gain or lose. If they think a successful pilot will be recognized and rewarded, they are more likely to try, but if failure might damage their career or reputation, they hesitate.

The third factor is attitudes. This is the general outlook a company has towards innovation. If a company has had bad experiences with new technology before, a negative attitude can spread and make people skeptical about future proposals. The fourth is cognitive factors, which include how people perceive risk and uncertainty. If there is not enough evidence that a certain technology works, or if it is hard to predict the outcomes, employees lean toward rejection. Evidence from trials and trusted references can help reduce this uncertainty.

The fifth group is social factors. People are influenced by their colleagues and peers, and often do not want to be the first mover. A respected worker inside the company can make a big difference by building trust and keeping momentum. Finally, there are organizational factors, such as leadership signals, collaboration, and how well a company learns from past projects. The study found that leadership and collaboration were rated strongly in many companies, but organizational learning was weaker. This means that pilots are sometimes run, but lessons are not shared effectively across the company, which slows down or even halts the adoption.

A key finding is that these psychological factors matter most at the early stages of adoption. This is the point where many technologies fail, long before they reach scaling or standardization. If a proposal is framed as a risky bet, managers are likely to say no. If it is framed as a low-risk learning exercise, with clear exit plans, then approval is more likely and this shows that framing and trust are as important as the technical qualities of the tool itself.

The study also provides practical advice. Companies can encourage adoption by creating a culture where trying new things is not punished. Leaders should publicly recognize well-designed pilots, even if the results are mixed, so that employees know they will not be blamed for testing. Vendors should bring credible data from similar contexts and find internal champions to support their technology. Organizations should also build better systems to capture lessons learned and spread successful practices across teams.

Compared with the U.S. and Nigerian cases, the Scottish study highlights the leadership and decision-making level of technology adoption. In the U.S., adoption was mainly about whether the organization has the capacity and structures to support new technology. In Nigeria, it was about how workers perceive usefulness and how that affects their satisfaction and productivity. In Scotland, the focus is on how managers and leaders think and feel when they face the uncertainty of a new proposal. This shows that adoption in oil and gas is shaped by three different layers: organizational systems, frontline worker experience, and leadership psychology.

The big takeaway from the Scottish study is that adopting new technology is not just a technical decision. It is also a psychological and cultural one. People do not only ask whether a tool works, they ask what happens to them and their team if it fails. By making it safe to experiment, by providing credible evidence, and by supporting courageous workers, companies can speed up adoption without sacrificing safety. If they fail to do this, even great technologies will get stuck at the first gate.

4.1.5 Discussion

When looking at the three cases of technology adoption in the oil and gas industry, the United States, Nigeria, and Scotland, it becomes clear that adoption depends on different factors in each country. Even though the studies were carried out in very different contexts, they often deal with similar types of technologies, such as automation, digital monitoring systems, seismic imaging, robotics, and simulation training. What differs is not so much the technology itself, but how organizations, workers, and leaders respond to them.

In the United States, adoption is strongly shaped by organizational systems and resources. The study there focused on technologies like hydraulic fracturing, horizontal drilling, seismic imaging, and automation systems. These tools have transformed American oil and gas production, but their adoption is successful only when companies have strong absorptive capacity, meaning they can recognize new knowledge and apply it. American companies are generally good at creating systems and processes for adoption, which explains why technologies such as fracking and horizontal drilling spread so quickly across the shale industry. But the study also showed that knowledge and resources alone are not enough. Adoption happens only when these are turned into real organizational support and when technologies clearly match the tasks that workers are doing. For example, digital monitoring tools are more likely to succeed if employees see that the data helps them work more efficiently rather than adding extra steps that might also be hard to learn.

In Nigeria, the focus is on the workers' perception of usefulness. Here, technologies like automation, robotics for heavy tasks, and virtual reality training systems play a big role. The study found that workers who believed these tools were genuinely useful felt more satisfied in their jobs and more productive. For example, robotic systems that reduce dangerous manual work were seen positively by employees, because they improved safety and comfort. Simulation and VR training was also welcomed, because it gave workers confidence to use complex tools without real-world risk. However, the weak point in Nigeria was commitment. Even if workers appreciated the technology, it did not necessarily make them more loyal to their company. Broader issues like low pay, lack of appreciation and limited training opportunities meant that employees often saw the technology as helpful for their tasks but not as a reason to stay long term.

Scotland provides a third perspective by focusing on the decision makers and managers who have the power to approve or block new technology. In the North Sea, companies are cautious and slow to adopt unless they are convinced of the benefits. The study highlights psychological factors that shape these early adoption decisions. Technologies like ROVs, subsea robotics, and advanced digital systems for monitoring offshore operations are available, but they are only adopted when leaders feel secure. If they fear reputational damage from failure, they tend to reject new projects. Decision makers prefer technologies that are supported by strong evidence, low-risk pilots, and credible champions within the company. For example, when an ROV system comes with proof of successful use in another North Sea project, managers feel more confident approving a pilot. But if the evidence is weak or uncertain, they hesitate. This shows how psychological safety and framing are central to Scottish adoption.

When comparing all three cases, it becomes clear that each country excels in one dimension but struggles in another. The U.S. is strongest in structures and resources, with the ability to scale up technologies like fracking and digital monitoring quickly when the organizational support is present. Nigeria is strongest in workers' openness to useful tools, where technologies that clearly improve satisfaction and safety, such as automation or VR training, are welcomed. Scotland is strongest in leadership and collaboration, but its weakness is the over-cautious mindset of decision makers, which often slows the adoption of subsea robotics and digital systems.

Weaknesses are also visible. The U.S. sometimes fails to translate knowledge into broad cultural support. Nigeria struggles with worker loyalty, as usefulness does not guarantee commitment. Scotland struggles most at the decision-making stage, where fear of failure prevents good technologies from being tested.

Looking at which technologies are more welcomed, the U.S. favors those that directly improve efficiency and productivity, such as horizontal drilling or seismic imaging. Nigeria favors those that improve safety and make physical work easier, such as robotics and VR training. Scotland favors those that come with strong evidence and low perceived risk, such as proven ROV systems or well-documented monitoring tools.

From these cases, improvements can be concluded. The U.S. could learn from Nigeria the importance of paying attention to the worker perspective. Even with strong systems, adoption will fail if workers feel technology only adds pressure. Nigeria could learn from the U.S. the importance of absorptive capacity and organizational learning, so that adoption becomes part of the company system rather than just the experience of individual workers. Scotland could learn from both. From the U.S., it could adopt stronger structures for systematic adoption. From Nigeria, it could learn that workers' perceptions of usefulness should not be ignored. This would help Scottish decision makers move beyond risk aversion and focus more on the value technologies bring.

Sustainability is another issue. In all three cases, sustainable adoption means not just trying a technology once but embedding it in long-term practices. In the U.S., this means ensuring systems are not only resource-rich but also inclusive of workers. In Nigeria, it means pairing technology with fair compensation, strong training, and clear career paths. In Scotland, it means creating a culture where pilots are treated as opportunities to learn rather than as personal risks for leaders.

Some practical recommendations drawn from all papers are that companies should continuously update working conditions to enhance productivity, increase efforts to promote employee commitment when adopting new technologies, and provide training using advanced methods like virtual reality or simulation apps. These steps would not only improve technology adoption but also ensure worker safety and reduce accidents in such a high-risk industry.

The transition to a digital and low-carbon oil and gas sector requires a workforce equipped with new skills. Companies should implement training programs in digital literacy, big data analytics, machine learning applications, and renewable energy technologies. Collaborations with universities and vocational institutions can help bridge the skills gap. In developing contexts such as Nigeria, international partnerships can also play a role in funding and delivering such training.

Collaboration between governments, energy companies, and startups is crucial for accelerating innovation. Public–private partnerships can fund pilot projects, share risks, and create testbeds for emerging technologies. For example, the U.S. has benefited from government-supported research programs, while Scotland's offshore wind sector grew through close industry–government collaboration. Replicating such models in Nigeria could help overcome resource limitations and regulatory gaps.

Regulation should balance safety and environmental protection with flexibility for innovation. Governments must design policies that allow companies to experiment with digital technologies and cleantech solutions without facing unnecessary delays. Adaptive frameworks can also help integrate renewables into oil and gas operations and ensure that cross-border projects run smoothly.

Startups are key drivers of technological progress in the industry, but they often lack access to funding and industry networks. Governments and large companies should support incubation programs, venture funds, and collaborative platforms where startups can test and scale their solutions. Encouraging innovation ecosystems will accelerate technology transfer and adoption.

While digital tools improve efficiency, the ultimate goal should also be to reduce the environmental footprint of oil and gas operations. Companies should integrate cleantech such as carbon capture, hybrid renewable systems, and methane emission reduction technologies into their strategies. Aligning with global carbon-neutral goals will also strengthen their position with investors and stakeholders.

As Dua (2025) investigates in his research, by using qualitative interviews with twenty senior leaders across the sector, he analyzes the experiences of oil and gas executives in adopting Industry 4.0 technologies. Industry 4.0 encompasses advanced digital tools such as artificial intelligence (AI), Internet of Things (IoT), robotics, big data, and automation, all of which hold significant potential to transform operational processes in the energy sector.
One of the central findings of the study is that executives view Industry 4.0 as a driver of efficiency, safety, and cost optimization, particularly through predictive maintenance and

real-time monitoring of equipment. For example, IoT sensors and machine learning models are being applied to detect anomalies in drilling and production systems before failures occur, thereby reducing downtime and operational risks.

However, the research also highlights a gap between interest and implementation. While executives express strong enthusiasm for digitalization, actual deployment remains uneven across companies. Organizations with established data infrastructures and a culture open to innovation are better positioned to integrate these technologies successfully. In contrast, firms relying on legacy systems face significant difficulties in aligning new tools with older infrastructures.

The challenges are not purely technical. The study identifies workforce skills, financial constraints, and organizational resistance as major barriers to adoption. Many employees lack the technical expertise to manage and interpret digital data streams, and this skills gap slows down adoption. Moreover, the high cost of technology investment, combined with volatile oil prices, discourages companies from committing to large-scale deployments. Resistance to change within organizations, particularly among staff accustomed to traditional methods, but also creates friction in the adoption process.

Importantly, the findings suggest that organizational readiness is a critical determinant of success. Companies that cultivate digital literacy, invest in training, and foster a culture of adaptability are more likely to realize the benefits of Industry 4.0 technologies. This reinforces the view that digital transformation in oil and gas is not only a technological challenge but also a human and organizational one (Dua, 2025).

The study concludes that for Industry 4.0 to reach its full potential in the sector, firms must address the socio-technical barriers—particularly workforce training and infrastructure modernization. Without bridging these gaps, the industry risks uneven progress, where only the most advanced companies fully benefit from digital innovation, while others lag behind. (Dua, 2025)

The adoption of emerging technologies in the oil and gas sector is driving significant improvements in efficiency, safety, and environmental performance. Leaders in the industry must stay abreast of these innovations and strategically implement them to remain competitive. By embracing AI, IoT, robotics, blockchain, and other cutting-edge technologies, the oil and gas sector can navigate the challenges of the 21st century and ensure a sustainable and profitable future.

In conclusion, the findings show that technology adoption in oil and gas is shaped by three different but complementary layers. In the United States, adoption depends on organizational structures and absorptive capacity. In Nigeria, it depends on workers' perceptions of usefulness and their satisfaction with technology. In Scotland, it depends on the psychology of leaders and their willingness to take risks. The most welcomed technologies in all three cases are those that improve efficiency, safety, or confidence, such as automation, seismic imaging, robotics, and VR training. But adoption is weakest where support systems, loyalty, or leadership confidence are missing.

An overall takeaway from the case studies is that technology only improves performance when workers believe in its usefulness and when companies provide the right support. In Nigeria's oil and gas sector, this is especially vital because the industry is so central to the economy and yet faces so many challenges. For students and managers alike, the takeaway is a common realisation: new machines and systems can help, but people's perceptions and experiences with them matter even more.

The lesson is that sustainable adoption requires balancing all three levels: structures, workers, and leadership. Oil and gas companies must combine resources, worker engagement, and leadership support to fully benefit from technologies. Only then can innovations move from being technical possibilities, to real, long-term improvements in performance and safety.

Chapter 5
Conclusions

5.1 Summary of Findings

This research explored the role of emerging technologies in the oil and gas industry and compared their adoption across three different national contexts: the United States, Scotland, and Nigeria. The study examined a wide range of technologies, including artificial intelligence, Internet of Things (IoT), robotics, blockchain, digital twins, cleantech solutions such as carbon capture and hydrogen, as well as connectivity and cloud computing. The analysis combined literature reviews, industry reports, and case studies to evaluate both the opportunities and challenges associated with these technologies.

The findings show that emerging technologies are reshaping the oil and gas industry by offering new ways to increase efficiency, reduce costs, improve safety, and support the transition toward cleaner energy. However, the pace and scope of adoption vary greatly by region.

The U.S. stands out as a global leader in technology adoption within oil and gas. It benefits from a strong research ecosystem, significant financial investment capacity, and close cooperation between energy companies, universities, and startups. U.S. operators are among the first to deploy advanced digital tools such as predictive maintenance using AI, digital twins for drilling optimization, and blockchain for supply chain transparency.

While Scotland is smaller in scale compared to the U.S., it has become a regional leader in renewable integration and offshore expertise. Its oil and gas industry is closely linked with the North Sea, but recent government strategies have also prioritized sustainability and the energy transition. This creates a unique environment where digital and cleantech innovations are applied not only to extend the life of oil and gas assets but also to support offshore wind and renewable projects.

Nigeria shows strong potential but faces significant challenges. The country has large reserves of oil and gas, and startups are beginning to appear in areas such as digital monitoring, equipment management, and clean energy solutions. However, infrastructure limitations, inconsistent regulatory frameworks, and limited funding slow down large-scale adoption. Despite these challenges, the Nigerian case highlights the importance of local innovation ecosystems and the potential for leapfrogging into new technologies when supported by international partnerships.

Across all three cases, startups were found to play a critical role. They provide agility, creativity, and specialized expertise that complement the larger operations of multinational oil companies. At the same time, the workforce dimension emerged as a crucial factor: without training and reskilling, many employees struggle to adapt to the digital tools and cleantech solutions being introduced.

The findings of this study have important implications for a wide range of stakeholders in the oil and gas sector. For oil and gas companies, technology adoption is more than an efficiency measure; it is a matter of long-term competitiveness and survival in a rapidly changing global energy landscape. Companies that invest in digitalization, automation, and cleantech can reduce operational costs, improve safety, and respond better to sustainability pressures. Those that delay may face declining relevance as investors and governments push for cleaner energy.

For governments and regulators, the research shows that supportive frameworks and incentives are essential. In advanced economies like the U.S. and Scotland, clear regulatory signals and funding programs have encouraged companies to innovate. In Nigeria, however, regulatory uncertainty and weak enforcement create risks that discourage investment. Stable and adaptable frameworks are therefore key to unlocking technological potential.

For technology developers and startups, the study highlights the need to design solutions that are scalable, affordable, and tailored to the realities of the oil and gas sector. Startups must consider factors such as cost sensitivity in developing economies, integration with existing infrastructure, and compliance with safety standards. Partnerships with established industry players can help them scale faster.

For the workforce, the research underscores the urgent need for continuous training. Many traditional roles are being reshaped by digitalization and automation. Without targeted upskilling in areas like data analytics, AI, and cleantech operations, workers risk being left behind.

Conversely, companies that invest in their employees' skills will benefit from smoother transitions and stronger organizational resilience.

5.2 Scope and Limitations

This research mainly looks at upstream, midstream, and downstream operations in the oil and gas industry, using information from secondary data sources. While this gives a good general overview, it doesn't fully show how things work in practice. Future studies could go deeper into the technical side, such as how new software is developed, how workers are trained to use it, and what challenges come up when applying new technologies in real situations, possible downsides, such as cybersecurity problems or difficulties managing large amounts of data.

There are also several interesting directions for future research. One important area could be the role of hydrogen as a cleaner alternative to fossil fuels, especially for heavy industries and transport. It would be useful to study what kind of infrastructure is needed to make hydrogen more widely used around the world. Another important topic is Carbon Capture, Utilization, and Storage (CCUS). Even though it has a lot of potential, it's still not clear how cost-effective or scalable it will be in the long run, so future research could focus on which regions and projects are best suited for it.

In developing countries, the role of startups is another topic that deserves more attention. For example, future studies could explore how innovation ecosystems in places like Nigeria can keep growing despite funding and infrastructure challenges, and how global partnerships could help. Finally, it's also important to consider the social side of these changes, how local communities feel about new technologies, and how shifts in the energy workforce might affect jobs and everyday life in oil-producing regions.

References

[1] Zand, M. (2024, July 10). *A comprehensive analysis of the evolution of the oil & gas industry: From past to present and future challenges*. International Conference of New Technologies in Oil, Gas and Petrochemical Engineering in Iran. https://www.researchgate.net/publication/382114342_A_Comprehensive_Analysis_of_the_Evolution_of_the_Oil_Gas_Industry_From_Past_to_Present_and_Future_Challenges

[2] Halaweh, M. (2013). *Emerging technology: What is it? Journal of Technology Management & Innovation, 8*(3), 108–115. https://doi.org/10.4067/S0718-27242013000300010

[3] Duggal, N. (2023, July). *Top 18 new technology trends for 2023*. Simplilearn. https://www.simplilearn.com/top-technology-trends-and-jobs-article

[4] Dennis, A. (2024, July). *Digital transformation of the oil & gas industry (2024)*. Whatfix. https://whatfix.com/blog/oil-gas-digital-transformation/

[5] AZTech Training & Consultancy. (2024). *Emerging technologies in the oil and gas sector*. https://aztechtraining.com/articles/emerging-technologies-in-the-oil-and-gas-sector

[6] Prestidge, K. L. (2022, February 1). *Digital transformation in the oil and gas industry: Challenges and potential solutions* [Master's thesis, MIT]. https://dspace.mit.edu/handle/1721.1/143178

[7] Sircar, A., Nair, A., Bist, N., & Yadav, K. (2022). *Digital twin in hydrocarbon industry. Petroleum Research, 8*(2), 270–278. https://doi.org/10.1016/j.ptlrs.2022.01.009

[8] UiPath Inc. (2025). *What is robotic process automation?* https://www.uipath.com/rpa/robotic-process-automation

[9] IBM. (2023, May 12). *What is the Internet of Things (IoT)?* https://www.ibm.com/think/topics/internet-of-things

[10] Brancaccio, E., & Serintel Srl. (2020). *Big data in oil and gas industry.* Serintel Srl. https://www.serintel.org/public/bigdataoilgas.pdf

[11] Kumar, R., et al. (2021). The role of additive manufacturing for biomedical applications: A critical review. *Journal of Manufacturing Processes, 64*, 828–850. https://doi.org/10.1016/j.jmapro.2021.02.022

[12] StartUs Insights. (2025, February 24). *Top 10 oil and gas industry trends in 2025*. https://www.startus-insights.com/innovators-guide/oil-and-gas-industry-trends/

[13] Antriksh, P. (2023). *Oil and gas market growth, industry developments [2030]*.
https://www.kingsresearch.com/oil-and-gas-market-177

[14] Frunzescu, D. (2019). Advanced techniques for determining parameters of interest in shale gas exploration. *SGEM International Multidisciplinary Scientific GeoConference Expo Proceedings*.
https://doi.org/10.5593/sgem2019/1.2/s06.078

[15] Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://doi.org/10.2307/249008

[16] *Determinants of technology adoption in US oil and gas industry*. (2021). *International Journal of Technology, Policy and Management, 21*(2), 104. https://doi.org/10.1504/IJTPM.2021.116512

[17] Bolodeoku, P. B., et al. (2022). Perceived usefulness of technology and multiple salient outcomes: The improbable case of oil and gas workers. *Heliyon, 8*(4), e09322. https://doi.org/10.1016/j.heliyon.2022.e09322

[18] Roberts, R., et al. (2021). Psychological factors influencing technology adoption: A case study from the oil and gas industry. *Technovation, 102*, 102219. https://doi.org/10.1016/j.technovation.2020.102219

[19] Dua, S. (2025). Exploring the experiences of oil and gas industry executives in embracing Industry 4.0: Insights, challenges, and strategies. *Computers & Industrial Engineering, 208*, 111377.
https://doi.org/10.1016/j.cie.2025.111377