

**ECONOMIC AND ENVIRONMENTAL EFFECTS OF ENERGY STORAGE INNOVATION AND MANAGEMENT OF CLEAN ENERGY IN OIL AND GAS INDUSTRY****<sup>1</sup>Dr. Nworgu, Kelechi Godson, <sup>2</sup>Dr. Collins Okechukwu Amadi & <sup>3</sup>Dr. Michael N. Obiora***Email: nworgugodson10@gmail.com, otukiri63@gmail.com, michael.obiora@komu.edu.ng***<sup>1&2</sup>Department of Sociology, Faculty of Social Sciences, University of Port Harcourt, Rivers State, Nigeria, <sup>3</sup>Department of Sociology, Faculty of Social Sciences Kingsley Ozumba Mbadiwe University, Ogboko, Imo State, Nigeria****ABSTRACT**

*At the view of transformative shift from obsolete generation of electricity are the innovations in energy storage technologies in key areas of economic and environmental activities, which are crucial in enhancing, integrating and management of clean energy resources. The paper investigated economic and environmental effects of energy storage innovations and management of clean energy in oil and gas industry. The objectives include to ascertain the effect of energy storage on the economy and environment in oil and gas industry, and to investigate the importance of managing clean energy in oil and gas operations. The diffusion innovation theory is adopted in this study. The descriptive research design was adopted and data were obtained from secondary sources on Canada, United States and Africa as a continent. The findings indicate that clean energy technologies are important for the improvement of oil and gas operations across the globe, national electricity grid, economic growth and preservation of environment in Canada, United States and Africa. Based on the findings, the study recommends that Governments and its regulatory agencies in oil and gas industry should formulate policies that promotes the integration and expansion of clean energy technologies in oil and gas operations across nations to boost economic activities and reduce the emissions of carbon and preserve the environment, and that management in oil and gas operations should design strategies that can be effectively and efficiently utilized in managing clean energy resources in oil and gas companies for production and storage activities, and to preserve the environment.*

**Keywords: Economic, Environmental, Effects, Energy Storage, Innovation, Management, Clean Energy, Oil and Gas, industry**

**INTRODUCTION**

The global drive for energy storage is critically undergoing a major transformative shift due to the need of addressing climate change issues, improved energy security, as well as to meet the increasing requirement for power in oil and gas sector. At the view of this purported transformative shift are the enhancement in energy storage technologies in key areas of economic and environmental activities, which appear very crucial in achieving the integration and management of clean energy sources, while mitigating issues of grid instability, and providing support to electrification of oil and gas sector (Aneke & Wang, 2016). This transition enables evaluation of energy storage innovations and technologies which becomes pivotal for nations to strive toward decarbonizing their energy structures and build more resilient modern infrastructures.

Technological advancement has enabled humans to explore the planet's natural resources such as in the innovation of energy sources, oil and gas, and other petroleum products like petrol, diesel, and kerosene, for the transforming of daily life, and empowering a wider aspect of humans' activities. Specifically, oil and gas industry play a significant impact on the status of global economy, sustainability of the environment, and the servicing of lives of millions of individuals in utilization of energy supplies. The high profitability potential of the oil and gas industry keeps attracting investors to the sector despite its volatility amidst energy transitions concerns. The demand for energy in oil and gas sector is among the largest in the world, and this has attracted billions of dollars in the investment into clean energy (Kulanov et. al., 2020).

The hydrocarbon or oil and gas industry usually partners with other stakeholders on issues of global energy supply and usage in areas involving exploration, extraction and storage of hydrocarbon resources below the surface of the Earth. Furthermore, energy storage technologies, power complex systems, logistics processes and multidisciplinary or multidimensional collaboration are also involved in these critical processes (Didenko et al., 2023). In recent times, the global energy technological landscape has undergone a series of transforming era that has marked growth in recognition of its sustainability as a crucial requirement for all active sectors of the economy. In addition, the upstream or downstream oil and gas sectors stands at a delicate juncture in facing the complex challenges that requires new approaches as well as responsible practices.

There are many environmental, health, economic, security, and social challenges in association with hydrocarbon operations (Robertson, 2017). The oil and gas industry faces unprecedented assessment on its attempts to minimize its environmental impacts while meeting global energy demands. The dynamic approach of sustainable energy storage is vital toward balancing economic growth and environmental footprints and responsibility. In an attempt toward eliminating carbon emissions and reducing ecosystem impacts, the initiative for the management of clean energy becomes a necessity in oil and gas industry in order to promote local community development as well as to foster global economies (Foster, 2020). More so, the responses by the oil and gas industry to these challenges narrates its adaptability and the need for a shift directed to sustainable global energy resources management within the hydrocarbon industry.

In association with hydrocarbon exploration activities and oil production operations are profound ecological impacts, which affects bioresources as well as the ecosystem health (Albeldawi, 2023). During oil and gas exploration and extraction, it is obvious that marine habitats and terrestrial environmental elements can have negative impacts (Thakur & Koul, 2022). A squared balance must be maintained in oil or gas industry operations in relation to usage and management of clean energy, as well as the sustainability of earth's robust biodiversity in order to protect the delicate arrays of the ecosystems in the industry's operations. The oil and gas industry have many areas that are conducive to the integration of clean energy technologies. The hydrocarbon production facilities are mainly situated in offshore, swamp and remote locations, and they use large amounts of electricity that are generated with renewable sources like wind and solar.

Clean energy technologies are already in skeletal use or are deeply integrated in certain oil and gas operational facilities. Furthermore, management of energy in the petroleum industry and associated decreases in costs for different clean energy technologies is shifting the economic advantage in favour of higher integration. More so, clean energy technologies are not applicable in all cases. Clean energy technologies must be environmentally friendly, economically competitive, reliable and commercially viable. In oil and gas sector, clean energy technology is being applied to solve the electricity challenges in the offshore operations and to supply the thermal energy needed for the enhanced oil recovery process Halabi et. al., (2015). Halabi et al. (2015) observed in a study that solar (clean) energy technologies were being used in the oil and gas industry, and that they had limitations. However, it was only solar energy among other clean energy technology used in either oil or gas industry. Therefore, it requires that further analysis should be made on other energy technologies like wind power and geothermal power. It is against this backdrop that this study seeks to investigate the economic and environmental effect of energy storage as well as to explore the importance of managing clean energy in oil and gas exploration and production activities.

**Objectives of the study consist:**

- i. To ascertain the effect of energy storage on the economy and environment in oil and gas industry.
- ii. To investigate the importance of managing clean energy in oil and gas operations.

**Research Questions**

- i. What is the effect of energy storage on the economy and environment in oil and gas industry?

- ii. What is the importance of managing clean energy in oil and gas operations?

### **Energy Storage in Canada, America, and Africa**

With a wider and multifaced geographical landscape, Canada appears to have a reservoir of energy arrays and abundant natural resources that are predominantly positioned. The country stands as a major forerunner in hydropower generation of rich energy and storage, harnessing the massive banks of its network of rivers. Therefore, hydropower, wind as well as solar among clean energy sources contribute immensely to the country's electricity power mix. More so, Canada as a prime inventing country have been exploring potential technologies by developing energy storage facilities as well as in advancing the grid systems to formalize further integrated clean energy as well as addressing the intermittency embedded in some clean sources. The energy storage innovation in Canada has massively been influenced by the activities of the country's oil and gas industry (Mansell & Schlenker, 2004). Therefore, the juxtaposition of the country's available and potential renewables as well as the existing basic fossil fuels highlights more openings and challenges that engender the nation as it drives to achieve equilibrium in growth of the economy amidst the call for environmental sustainability and availability of clean energy (Hossain, Singh, Sharma, Apostu, & Bansal, 2023).

America is also a substantive world economic pioneer of clean energy that provides a high-level energy generation and storage system characterized by multiple technologies of energy sources. The country has rich coal, gas, as well as heavy nuclear power investment which have historical evidences as well as significantly played more roles across the United States energy matrix and storage (Marshall, 2017). Furthermore, there are evidences of a major shift towards sustainable and cleaner energy shift in recent times (Adeniyi et. al., 2020). Clean energy, such as wind or solar, accounts for notable growth that is highly driven by supportive and fair play policies in energy technology as well as a decline in costs of production (Timilsina, Kurdgelashvili, & Narbel, 2012). Moreover, the United States is stationed at the central view of innovative technologies in energy generation and storage, as well as exploring its grid-scale and level in battery systems as well as several advanced energy storage solutions. In addition, the challenge braces on the effective integration most technologies into a broadened and interconnected grid sustenance while also promoting reliability or activating resilience in the system (Sen & Ganguly, 2017).

Africa, as an energy consuming continent is plunged into demographic issues as well as divergent forms of economic conditions, has been facing different levels of energy challenges as well as opportunities (Rotberg, 2013). Several African nations still lack access to a reliable source of energy, and finds it difficult to affordable or provide electricity to its population. As a result, there is a growing attempts and emphasis on developing, expanding and sustaining a reliable energy structure with infrastructural modifications as it focuses on a more decentralized approach and off-grid panaceas (Bhattacharyya & Palit, 2021). Clean energy such as solar as well as wind, offers tremendous consequences toward meeting Africa's clean energy demands. Innovative potential, like central mobile payment systems as well as community-centred clean energy facilities, are growing speedily as the crux for Africa's energy development as argued by (Aliyu, Modu, & Tan, 2018). In addition, as Africa follows the path towards sustainable electrification, initiating the efforts toward integration of energy storage technologies becomes a boost to enhancement of grid stability as well as a support for intermittent clean energy pathways. In Africa, the energy frameworks and needs are intricately attached to social, economic, as well as environmental determinants. Proper perception of the energy landscapes and inherit factors are essential for adequate assessment of the feasible impacts of energy storage technologies as well as ensuring that developing of solutions is in tandem with each country's particular characteristics, aspirations and needs.

### **Types of Sustainable Energy Storage Technologies**

Energy storage refers to capture of energy that is needed and produced at a particular time in one way or the other for use at a given time in another form. Energy can occur in several forms and phases naturally which can be converted into another form for storage. However, the common

energy storage forms are batteries and dams. For example, living organisms can store energy in the form of starch and glycogen. Animals like camels have large capacity to store water in order to survive in deserts. More so, unique clean energy sources like water, solar and wind require certain energy storage system to have extra energy during high demand or low demand, and to release energy whenever there is low availability in high demand periods. Furthermore, energy storage systems can regulate fluctuating wind or solar energies Funabashi (2016). For energy storage, making use of batteries is seen as the most unique and effective ways to stabilize electricity availability (May, Davidson, & Monahov, 2018). Therefore, energy storage and transportation are critical elements for stability of energy to the consumers. The generation of electrical energy is shifting profoundly across the world because of availability of Greenhouse gases (GHG) being produced by fossil fuels (Panwar, Chanda & Mohanpurkar, 2019).

There are various energy storage technologies that stimulate individual businesses, corporate bodies and localities choice. Some these forms of energy storage systems have been found to be sustainable in oil and gas industry. Among these energy storage systems include: Battery Storage Systems: This technology is seen as a corner piece in the innovation among other energy storage systems. An example of this technology is Lithium-ion batteries which have also emerged to have more prominence because of their high potential energy capacity, density, durability, latency, and cost advantage (Zhang, Wei, Cao, & Lin, 2018). However, these series of batteries can be utilized in different locality, from small to medium scale industrial and residential facilities to mega grid-related installations. More so, other types of energy batteries, include sodium-ion batteries, which are still under massive exploration, offering high benefits for particular uses (Olabi et. al., 2023).

Pumped Hydro Energy Storage technological system remains a prominent and generally deployed ways of key grid-scale energy production and storage system. This type of technology mainly uses the gravitational or movement of water channels, such as the release of water out of a lower reservoir level to higher reservoir in times of low power demand. At peak of the demand, the water in the reservoir is released, and it flows downhill and drives turbines to generate energy in form of electricity or power. Pumped hydro energy storage is well sustainable due its high, reliability, efficiency and longtime cycle life (Akinyele & Rayudu, 2014).

Thermal Energy Storage system offloads certain forms of storing of heat energy. In such situation, Molten salt can be used in dedicated solar power panel installations to store or produce thermal energy. This system provides steady electricity generation even as the sun goes down. In addition, phase change elements and sensible heat storage are some thermal energy storage systems applied in different ways like solar water heaters, space heating, and industrial processes (Vignarooban, Xu, Arvay, Hsu, & Kannan, 2015). Another technology is the Flywheel Energy Storage system. This technology stores energy in the form of kinetic energy. This spine the rotor within a vacuum or low-friction kind of enclosure that can retain power. At the moment electricity is needed, the motion of rotor's kinetic energy is converted and released back as electricity. Flywheels can offer rapid simulation response and can also allow grid sustainability by contributing short-time energy storage (Amiryar & Pullen, 2017).

Compressed air energy system involves the compressed system of air storage in underground structures as well as other facilities. During times that electricity is in high demand, the compressed air system releases and navigates through turbines and activate generating of electricity. This technology is recognized for its sustainability as well as the capability to escalate massive-scale energy saving, thereby making it a more suitable clean energy source (Gür, 2018). More so, hydrogen storage technology is a unique system that is gaining recognition as a potential energy medium that provides large-scale and long-term energy storage. To this end, electrolysis is utilized to make hydrogen emanate from excessive electricity, and as it is stored, the hydrogen will be converted also into electric power through fuel cells elements and any other ways that may be required. Hydrogen storage is used mostly where direct sources of electrification is usually challenging (Johnson et. al., 2023).

### **Energy Storage Effects on the Economy**

In consideration of energy storage technologies, the associated economic effects are multifaceted. This is because integration of grid-scale and longtime-scale of energy storing system often promotes either the stability and capability of the electricity grid system, and reduces the call for higher or costly grid facility and structure upgrades which also influences the facilitation of system running cost reduction for both utilities, and level of consumers. Furthermore, proper examination of the growing energy storage sector provides opportunities for job creation, which is visible in areas of manufacturing, installation, upgrading, and maintenance of energy storage systems. Furthermore, the effects on the economy have advantages that helps to improving, expanding and developing of sustainable energy storage sector, that is attractive to more investors, while also fostering potential innovation. Hence, as energy systems of storage advances, it will continue to gradually become a key player for the integration of clean energy sources, even as it is bolstering most of the developed countries, particularly, Canada in a central position in the global clean energy market and industry (Peters, Axsen, & Mallett, 2018).

America is one of the leading countries experiencing the economic effects of energy storage solutions. There are evidences in the evolving and growing energy storage capacity in United States. The massive use of battery system of storage mainly contributes to national grid reliability, and the reduction for the demand of Peaker plants installations as well as minimization of the economic costs related with power insufficiencies and outages. More so, the expansion of the energy storage technologies promotes economic activity, ensures jobs creation and also supports local economic systems. Energy storage industry plays an important role in upgrading or improving the economic sustainability of clean energy structures. However, mitigating the complex nature of wind or solar projects, these energy storage technologies can contribute to the viability and stability of electricity power supply, while also attracting more investors in clean energy storage technologies (Wali et. al., 2024).

Africa also have a share of experience in the economic effects of emerging energy storage systems which are linked to efforts of addressing energy accessibility issues. However, off-grid as well as decentralized energy system contributes in empowering communities as it provides reliable and sustainable electricity as well as catalyzing economic advancement. In addition, small-scale energy facilities, such as solar energy systems with storage battery can assist in the development of local business projects, and also improves people's livelihood. Meanwhile, the ability to afford energy storage system and innovative financial cost models opens up opportunities in the economy for businesses, individuals, investors and corporate bodies. As Africa contemplates to grow or advance modern energy storage infrastructure, there are potential economic gains in adopting trending energy storage systems that makes it more instrumental in the fascinating of a more viable and sustainable energy capacity in the energy industry (Pachauri et. al., 2012).

### **Energy Storage Effects on the Environment**

The perspective of energy storage in Canada and its effect on the environment are in tandem with the country's commitment toward the reduction of carbon gas emissions. In an attempt to facilitate the integrating of clean energy sources, it is perceived that energy storage system contributes to the rapid discharge of fossil fuel energy generation system, and the lowering of overall carbon gas emissions. Furthermore, growth in battery systems enhances and promote the regular electrification of carriage system, and the reduction of reliance on traditional engines of combustion. Therefore, the key environmental advantages expand to the sustainability of natural resources, mainly in areas with the prevalence of hydropower. Energy storage technologies assist in providing a better application of clean energy resources, reducing ecological forms disruption that are linked with other varieties of clean energy sustainable generation according to the argument by (Janzen, Davis, & Kumar, 2020). Further, the environmental experiences of sustainable energy storage systems in US are clearly essential in ascertaining the clean energy systems goals as posited by (Dell & Rand, 2001). Utilization of battery storage system and other common technologies can provide support to

the transition out of fossil fuel-based engines, enhancement of air quality system and reduction of carbon emissions as posited by (Fitch, 2019). More so, the integration of energy storage facilities through clean energy infrastructures can improve the sustainability and viability of the complete energy storage system. However, utilizing of the promoted electric vehicle technology and batteries for sustainable energy storage forms and applications spreads as the environmental benefits across all industry. As the transportation industry embraces the rolling out of electric vehicles, batteries' life cycles the ecological impact appears to be more favorable to the environment (Faria et. al., 2013).

In African perspective, environmental perceptions of energy storage solutions are interconnected with the goal to move beyond the traditional forms of energy developmental struggles (Ofori-Amoah, 2020). The promotion of a decentralized or off-grid systems, storing of energy can minimize the dependence on diesel plants, generators or other polluting engines in local areas for electricity (López-Castrillón, Sepúlveda, & Mattar, 2021). However, this can mitigate the constant degradation of the environment caused by fumes of generators, and improves ecological conditions as well as air quality. Therefore, adopting and sustaining clean energy technology that are supported by energy storage technologies in Africa, that are in connection with global projects in combating climate change and ensuring the sustainable development of the environment (Victor & Great, 2021). Moreover, Africa seeks to spread its energy infrastructure, promote and emphasize more on sustainable and environmentally friendly technologies as it becomes more imperative for it to have long-term environmentally friendly impacts (Omisore, 2018).

### **Imperatives of Managing Clean Energy in Oil and Gas Operations**

The acceptance, adoption, implementation and management of clean energy as a trending storage technology represent entire interconnectivity or interlink between certain technological innovations, energy advancements, economic as well as environmental considerations, as well as regulatory frameworks. Pondering on the prevailing status of the unique technologies that are promoted in Canada, America, and Africa which offers more understanding into regional energy landscapes as well as how it trends globally. Hence, in Canada, there is great commitment in utilization of clean energy system and its broad related resources that influences the efforts in the adoption of trending energy storage infrastructure in the country. There are pioneers inculcating the knowledge of energy storage, and creating more awareness of developing as well as improving the national grid, and that leverages on other technological storage systems. There are progressive energy policies in Canada, as well as financial or cost incentives that keep encouraging the application of series of energy storage systems in both utility, business and community base. From microgrid facilities to combining clean energy system with innovations of energy storage, there is gain of traction in local and off-grid locations, and that enhances energy reliability. Moreover, the vast geographical landscape of Canada contributes to some logistic issues, requiring added creative approaches that can enable to efficiently deploy energy technologies across various areas (Choudhury, 2022). Furthermore, America, have long adopted energy storage approaches, which has made the country to experience significant growth in energy storage due to the link between federal as well as state-based policies, low costs effect, and a more resilient focus on national grid improvement.

Oil companies have started making efforts to minimize carbon emissions via improving on energy efficiency in oil and gas operations and products, heavily investing in clean energy such as solar, wind, biomass, geothermal, hydro-power, and marine energy, and this increases the role of gas in production, and investing in new low-carbon emissions technologies like electric vehicles, hydrogen technologies, and facilities for carbon capture and storage (CCS). Oil companies strategizes by navigating the energy transition through achieving reduction in operational carbon emissions, utilization of clean energy, developing low-carbon mobility systems, commercialization of carbon emissions capture and storage system (CCS), and innovating technologies that uses hydrogen for power generation and in transportation system. From both an environmental and an economic perspective, IOCs have an incentive to reduce emissions. Companies in oil and gas sector are

currently facing more pressure from society, government and shareholders to reduce carbon emissions to reduce their impacts to climate change.

Oil and gas output, operations and resources are significant concerns of our energy needs and economic expectations in future. (U.S. Energy Information Administration, 2021). Furthermore, there is global concerns to address environmental pressures and the benefits of clean energy to reduce the impacts of energy sources on the environment, and the increasing of operational efficiencies, and conservation of oil and gas resources on the environment are pressuring the oil and gas sector to ponder on energy implementing clean technologies management into their regular operations (Domonoske, 2021). Hence, the rapid fall in the price of affording clean energy technologies in recent times have made clean energy more attractive than in the past, and the interfacing of conventional generation of power with clean energy in oil and gas industry could provide a more feasible and economically attractive and environmentally friendly solutions to the reduction of carbon emissions. This is a way of meeting the constant need of oil and gas in sector and the propensity of energy required for oil and gas field operations while intervening for emissions reduction goals and reducing the environmental burdens involved toward integrating clean energy technologies into oil and gas industry operations as observed by (Ericson, Engel-Cox, & Arent, 2019). To preserve energy for future generations, it is important to ensure that the current policies are maintained and the energy resources are managed efficiently as well as effectively. The requirement for energy is for both now and, in the future. If energy waste is prevented, extraction and production processes can be optimized. Energy is needed toward increasing production of oil wells, reservoirs and improvement in oil recovery processes (Hassan et. al., 2020). Furthermore, the development of certain strategies, as well as the sustainable practices that emphasizes efficient energy resource management is meritoriously helpful to companies, economies and environment that heavily depend on energy resources utilization as a key component of growing economically, and sustainability of the environment (Ionescu, 2021). In the context of sustainable energy resources management, there is the perception that associated risk of investments could reduce with the evolution of the energy storage landscape in oil and gas sector. However, developing a balance of equilibrium between energy resources, energy supply, economic growth and environmental preservation, as well as the well-being of future generations is possible as the oil and gas industrial operations embraces responsible and efficient energy resources management

### **Theoretical Framework**

The diffusion innovation theory propounded by Rogers (1962) was utilized to buttress the study further. Diffusion of Innovation theory explains the need for adoption of innovation in several sectors including oil and gas, energy, agriculture, manufacturing, and information systems, among others. According to Rogers (1995, p. 11), diffusion is "the process by which an innovation is communicated through certain channels over time among the members of a social system"; while an innovation is "an idea, practice, or object that is perceived as new by an individual or another unit of adoption". Diffusion of Innovation theory believes in five constructs that influence the adoption of technology. The constructs include complexity, observability, compatibility, tri-ability and relative advantage Rogers (1995). The theory provides the process of innovation diffusion in five stages such as knowledge, persuasion, decision, implementation and confirmation. The theory categorizes the users of a particular technology into innovators, early adopters, early majority, late majority and laggards Roger (2003). The theory further claims that the conditions that can affect innovation adoption may include innovativeness, norms of social systems, previous practice and felt needs as in the demand of energy for companies, communities and other utility basis.

### **MATERIALS AND METHODS**

The study adopts descriptive survey design, and data were retrieved from secondary sources such as journals. Further, the data obtained deliberates on the advancement of energy storage systems

in oil and gas activities in Canada, America and African. It also explores data on clean energy management efforts in oil and gas sector for sustainable environment in different countries.

## **RESULTS AND DISCUSSIONS**

Results indicate that clean energy technologies are important for the improvement of national grid, economic and job growth as well as the preservation of environment in Canada, America and Africa among other developed and developing countries. Clean energy is cost optimal in the oil and gas industry. The reduction of carbon emission in the atmosphere guarantees a safer and sustainable environment as well as contributing to a healthy society, and it also result to providing value for the clean energy storage technologies. Clean energy storage technologies present opportunities for employment and economic advancement in society as its utilization expands across countries, companies, cities, and communities that had experienced epileptic electricity supplies in some African countries.

## **Conclusion**

The rise of energy storage innovation in both Canada, America, as well as Africa oil and sector demonstrates the promise fulfillment and efforts exerted for the designing of sustainable energy systems that is necessary for economic development and environmentally friendly interface between clean energy storage and oil and gas operations. The trending technological progress in battery type of storage, and the emergence of electric motors innovations are trajectory advancement across a broader energy landscape. The economic importance of energy usage in oil and gas sector, and the environmental impacts of energy storage technologies are evident in oil or gas work locations, with advantages ranging from creating of jobs to minimizing of greenhouse gas or carbon emissions. The future scenario openly indicates a continued efforts on improving existing technologies, exploring more novel technologies, as well as aligning with regulatory frameworks that support industry growth. Therefore, to ensure the stability, efficiency, and cost-effective operations in oil and gas sector, and the energy storage solutions, more effective, improved and enhanced optimization techniques are still a necessity in the provision of clean energy for electrification and sustainability of the economy.

## **Recommendations**

The following recommendations are provided in this study:

- i. Government and its regulatory agencies in oil and gas industry should formulate policies that promotes the integration and expansion of clean energy technologies in oil and gas operations across nations to boost economic activities and reduce the emissions of carbon in the air and preserve the environment.
- ii. Management and leaders in oil and gas operation should design strategies that can be effectively and efficiently utilized in managing clean energy resources that are used by the oil companies in oil and gas exploration, production and storage activities in order to preserve the environment and biodiversity elements.
- iii. Government should interface with stakeholders and manufacturers of energy batteries and other components in the developing of energy structures to reduce the financial cost and burden of purchasing clean energy facilities, and that the sale of the supportive devices should be open to all countries despite their economic and financial capacity.
- iv. Government should complement the efforts of the private sector by reducing taxes and tariffs imposed on imported clean energy technology storage facilities to encourage companies and other importers to import the required accessories for erecting clean energy infrastructures to ensure that electricity is affordable at reduced cost.

## REFERENCES

- Adeniyi, O., Ngozichukwu, B., Adeniyi, M., Olutoye, M., Musa, U. & Ibrahim, M. (2020). Power generation from melon seed husk biochar using fuel cell. *Ghana Journal of Science*, 61(2), pp. 38-44.
- Akinyele, D. O. & Rayudu, R. K. (2014). Review of energy storage technologies for sustainable power networks. *Sustainable energy technologies and assessments*, 8, pp. 74-91.
- Albeldawi, M. (2023). Environmental impacts and mitigation measures of offshore oil and gas activities. *In Developments in Petroleum Science*, p. 78
- Aliyu, A. K., Modu, B. & Tan, C. W. (2018). A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, 81, pp. 2502-2518.
- Amiryar, M. E. & Pullen, K. R. (2017). A review of flywheel energy storage system technologies and their applications. *Applied Sciences*, 7(3), pp. 286-280.
- Aneke, M. & Wang, M. (2016). Energy storage technologies and real-life applications—A state of the art review. *Applied Energy*, 179, pp. 350-377.
- Bhattacharyya, S. & Palit, D. (2021). A critical review of literature on the nexus between central grid and off-grid solutions for expanding access to electricity in Sub-Saharan Africa and South Asia. *Renewable and Sustainable Energy Reviews*, 141, 110792.
- Choudhury, S. (2022). Review of energy storage system technologies integration to microgrid: Types, control strategies, issues, and future prospects. *Journal of Energy Storage*, 48, 103966.
- Dell, R. M. & Rand, D. A. J. (2001). Energy storage—a key technology for global energy sustainability. *Journal of power sources*, 100(1-2), pp. 2-17.
- Didenko, N., Skripnuk, D., Merkulov, V., Kikkas, K. N. & Skripniuk, K. (2023). Methodology for the Formation of a Digital Model of the Life Cycle of an Offshore Oil and Gas Platform. *Resources*, 12(8), p. 86.
- Domonoske, C. (2021). Big Oil (Probably) Isn't Going Away Anytime Soon. But It's Definitely Changing. *NPR.org (blog)*. <https://www.npr.org>
- Ericson, S. Jill & Doug A. (2019). Approaches for Integrating Renewable Energy Technologies in Oil and Gas Operations. White Paper NREL/TP-6A50-72842. Colorado, USA: *The Joint Institute for Strategic Energy Analysis*. <https://www.nrel.gov/docs/fy19osti/72842.pdf>
- Faria, R., Marques, P., Moura, P., Freire, F., Delgado, J. & De Almeida, A. T. (2013). Impact of the electricity mix and use profile in the life-cycle assessment of electric vehicles. *Renewable and Sustainable Energy Reviews*, 24, pp. 271- 287.
- Fitch, E. (2019). The Ability of Hydrogen Energy Storage to Replace Natural Gas Peaker Plants in the 2030 *Time Frame*.

- Foster, G. (2020). Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts. *Resources, Conservation and Recycling*.
- Gür, T. M. (2018). Review of electrical energy storage technologies, materials and systems: challenges and prospects for large-scale grid storage. *Energy & Environmental Science*, 11(10), pp. 2696-2767.
- Halabi, T., Fung, B. C. & AlMamoori, S. (2015). School of information technology. Deakin University.
- Hassan, A. H., O'Donoghue, L., Sánchez-Canales, V., Corberán, J. M., Payá, J. & Jockenhöfer, H. (2020). Thermodynamic analysis of high-temperature pumped thermal energy storage systems: Refrigerant selection, performance and limitations. *Energy Rep.* 6, pp. 147–159.
- Hossain, M. R., Singh, S., Sharma, G. D., Apostu, S.-A. & Bansal, P. (2023). Overcoming the shock of energy depletion for energy policy? Tracing the missing link between energy depletion, renewable energy development and decarbonization in the USA. *Energy Policy*, 174.
- Ionescu, L. (2021). Transitioning to a low-carbon economy: Green financial behavior, climate change mitigation, and environmental energy sustainability. *Geopolitics, History, and International Relations*, 13(1), p. 86.
- Janzen, R., Davis, M. & Kumar, A. (2020). Greenhouse gas emission abatement potential and associated costs of integrating renewable and low carbon energy technologies into the Canadian oil sands. *Journal of Cleaner Production*, p. 272.
- Johnson, D., Pranada, E., Yoo, R., Uwadiunor, E., Ngozichukwu, B. & Djire, A. (2023). Review and Perspective on Transition Metal Electrocatalysts Toward Carbon-Neutral Energy. *Energy & Fuels*, 37(3), pp. 1545-1576.
- Kulanov, A., Issakhova, A., Koshkina, O., Issakhova, P. & Karshalova, A. (2020). Venture financing and the fuel and energy complex: Investing in alternative energy. *International Journal of Energy Economics and Policy*, 10(5), pp. 531–538.
- López-Castrillón, W., Sepúlveda, H. H. & Mattar, C. (2021). Off-grid hybrid electrical generation systems in remote communities: Trends and characteristics in sustainability solutions. *Sustainability*, 13(11), pp. 56-58.
- Mansell, R. L. & Schlenker, M. R. C. (2004). Energy and the Alberta economy: past and future impacts and implications. *Gas*, 35(40),
- Marshall, L. (2017). Nuclear Renaissance? Contemporary Geography of the US Nuclear Energy Industry.
- Ofori-Amoah, B. (2020). Disruptive technologies, sustainable energy generation and storage as forms of green economy. *Disruptive Technologies, Innovation and Development in Africa*, pp. 85-113.
- Olabi, A. G., Allam, M. A., Abdelkareem, M. A., Deepa, T., Alami, A. H., Abbas, Q., Sayed, E. T.

- (2023). Redox Flow Batteries: Recent Development in Main Components, Emerging Technologies, Diagnostic Techniques, Large-Scale Applications, and Challenges and Barriers. *Batteries*, 9(8), p. 409.
- Omisore, A. G. (2018). Attaining Sustainable Development Goals in sub-Saharan Africa; The need to address environmental challenges. *Environmental development*, 25, pp. 138-145.
- Pachauri, S., Brew-Hammond, A., Barnes, D. F., Bouille, D. H., Gitonga, S., Modi, V. & Zerrifi, H. (2012). Energy access for development.
- Panwar M, Chanda S, Mohanpurkar M. (2019). Integration of flow battery for resilience enhancement of advanced distribution grids. *International Journal Electrical Power Energy System*.
- Peters, D., Aksen, J. & Mallett, A. (2018). The role of environmental framing in socio-political acceptance of smart grid: The case of British Columbia, Canada. *Renewable and Sustainable Energy Reviews*, 82, pp. 1939-1951.
- Robertson, J. O. & Chilingar, G. V. (2017). Environmental Aspects of Oil and Gas Production. In *Environmental Aspects of Oil and Gas Production*.
- Rogers, E.M. (1995). *Diffusion of Innovations*. 4th Edition. The Free Press. New York.
- Rogers, E.M. (2003). *Diffusion of Innovations*. 5th Edition. The Free Press. New York
- Rotberg, R. (2013). *Africa emerges: Consummate challenges, abundant opportunities*: John Wiley & Sons.
- Sen, S. & Ganguly, S. (2017). Opportunities, barriers and issues with renewable energy development—A discussion. *Renewable and Sustainable Energy Reviews*, 69, pp. 1170-1181.
- Thakur, J., de Almeida, C. M. L. & Baskar, A. G. (2022). Electric vehicle batteries for a circular economy: Second life batteries as residential stationary storage. *Journal of Cleaner Production*, p. 375.
- Timilsina, G. R., Kurdgelashvili, L. & Narbel, P. A. (2012). Solar energy: Markets, economics and policies. *Renewable and Sustainable Energy Reviews*, 16(1), pp. 449-465.
- U.S. Energy Information Administration. 2019. Delaware Formation Structure Map (Delaware Basin). Maps: *Oil and Gas Exploration, Resources, and Production*.
- Victor, E. & Great C, U. (2021). The Role of Alkaline/alkaline Earth Metal Oxides in CO<sub>2</sub> Capture: A Concise Review. *Journal of Energy Research and Reviews*, 9(3), pp. 46-64.
- Vignarooban, K., Xu, X., Arvay, A., Hsu, K. & Kannan, A. M. (2015). Heat transfer fluids for concentrating solar power systems—a review. *Applied Energy*, 146, pp. 383-396.
- Wali, S., Hannan, M., Ker, P. J., Rahman, S., Le, K. N., Begum, R. & Mahlia, T. I. (2024). Grid-connected lithium-ion battery energy storage system towards sustainable energy: A patent landscape analysis and technology updates. *Journal of Energy Storage*, p. 77.

Zhang, C., Wei, Y. L., Cao, P. F. & Lin, M. C. (2018). Energy storage system: Current studies on batteries and power condition system. *Renewable and Sustainable Energy Reviews*, 82, pp. 3091-3106.