Leveraging Geospatial Planning and Market Intelligence to Accelerate Off-Grid Gas-to-Power Deployment

PAUL UCHE DIDI[1], OLOLADE SHUKRAH ABASS[2], OLUWATOSIN BALOGUN[3]
[1, 2, 3]*Independent Researcher, Lagos, Nigeria*

Abstract- Off-grid gas-to-power solutions are emerging as a critical component in the global push for universal energy access, particularly in regions where extending the centralized grid is technically or economically unfeasible. These systems, which utilize natural gas—including compressed natural gas (CNG) and liquefied natural gas (LNG)—to generate decentralized electricity, offer a cleaner, more reliable alternative to traditional diesel generators. They are especially suited to industrial clusters, commercial zones, agricultural operations, and remote communities that suffer from energy poverty and under-electrification. A major challenge in scaling off-grid gas-to-power deployment lies in the identification of high-impact locations where projects are both technically feasible and economically viable. This explores how geospatial data—such as infrastructure maps, population density, and proximity to gas pipelines—combined with market intelligence—such as energy demand profiles, customer segmentation, and willingness-to-pay—can optimize project siting and investment decisions. By integrating spatial analytics with socioeconomic and regulatory data, stakeholders can more effectively prioritize areas with the greatest need and potential return. This proposes a conceptual framework that merges geospatial planning with market intelligence to guide decision-making across the deployment lifecycle—from site selection to project validation and risk assessment. The framework incorporates layered data inputs and AI-driven modeling to streamline project targeting, enabling governments, investors, and developers to align energy supply with latent demand. The integrated approach has the potential to significantly accelerate energy access while stimulating local economic growth and industrial productivity. It also enhances the bankability of off-grid gas-to-power projects by reducing siting risk and improving demand forecasting. Ultimately, this research contributes to the development of a scalable, data-driven methodology for energy planning in emerging markets, positioning off-grid gas-to-power as a viable pathway toward sustainable and inclusive electrification.

Indexed Terms- Leveraging, Geospatial planning Market intelligence, Accelerate, Off-grid, Gas-to-power deployment

I. INTRODUCTION

Off-grid gas-to-power systems are gaining recognition as a viable and strategic solution for addressing electricity deficits in regions where centralized grid extension remains impractical or cost-prohibitive (Otokiti, 2019; SHARMA *et al*., 2019). These systems utilize natural gas—either in compressed (CNG) or liquefied (LNG) form—as a cleaner, more efficient fuel source for decentralized power generation. In energy-deficient regions, especially in parts of sub-Saharan Africa, Southeast Asia, and Latin America, off-grid gas-to-power infrastructure offers a resilient alternative to diesel generators, enabling localized electrification for industries, rural communities, and commercial enterprises (Lawal *et al*., 2014; Amos *et al*., 2014). Their scalability and reliability make them particularly suitable for rapidly electrifying underserved zones while contributing to environmental sustainability goals (Akinbola and Otokiti, 2012; Otokiti, 2017).

Despite their potential, off-grid gas-to-power deployments face significant barriers. Foremost among these are infrastructure gaps, such as limited access to gas transportation and storage facilities, as well as the lack of last-mile distribution networks (Ajonbadi *et al*., 2015; Otokiti, 2017). Economic risks also loom large, including uncertainties in fuel pricing, customer creditworthiness, and return on investment in low-demand or low-income areas. Furthermore, inefficiencies in planning and site selection hinder the timely and cost-effective rollout of these systems (Otokiti, 2017; Otokiti and Akorede, 2018). In many cases, deployments are not guided by comprehensive data, leading to suboptimal placement, underutilization of assets, and unmet demand. The fragmented nature of energy data in developing economies exacerbates these issues, further delaying project development and scaling.

In this context, geospatial planning and market intelligence emerge as essential tools for accelerating and de-risking off-grid gas-to-power deployments. Geospatial analysis leverages geographic information system (GIS) technology to map energy demand, infrastructure availability, and environmental constraints. When combined with granular market intelligence—such as population density, economic activity, customer segmentation, and willingness-to-pay—this spatial approach enables a holistic assessment of potential deployment sites (Otokiti and Akinbola, 2013; Ajonbadi *et al*., 2016). The integration of these tools allows for the identification of high-priority zones where off-grid gas-to-power projects can achieve maximum impact and commercial viability.

The rationale for this lies in the urgent need to develop more strategic, data-informed methods for energy infrastructure planning in emerging markets. By embedding geospatial and market intelligence into the deployment process, developers, policymakers, and financiers can make better-informed decisions, reduce project risks, and enhance the sustainability of energy access interventions. This approach aligns with broader development objectives, including the United Nations Sustainable Development Goal 7 (affordable and clean energy), and supports national energy transition strategies.

The objective of this, is to design and present an integrated framework that leverages geospatial planning and market intelligence to optimize the siting and rollout of off-grid gas-to-power systems. It aims to examine key data layers required for accurate planning, evaluate the integration of technical and socioeconomic datasets, and explore the use of advanced analytics for predictive decision-making. This also provides illustrative case examples to demonstrate the practical application of the framework and its potential to enhance energy access, promote economic development, and support the broader clean energy transition. By addressing the persistent gaps in planning and market understanding, this research seeks to contribute a replicable, evidence-based methodology for targeted off-grid energy interventions in resource-constrained settings (FAGBORE *et al*., 2020; Nwani *et al*., 2020).

II. METHODOLOGY

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology was employed to conduct a systematic review on leveraging geospatial planning and market intelligence to accelerate off-grid gas-to-power deployment. This approach enables the synthesis of existing evidence, identification of knowledge gaps, and clarification of methodological patterns that support the strategic deployment of decentralized gas-to-power systems, particularly in underserved and energy-insecure regions.

The literature search was conducted across major academic databases including Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar, complemented by grey literature from energy agencies, development institutions, and industry reports. The time frame of publications ranged from 2005 to 2025 to capture both foundational and recent advancements in geospatial analytics, energy access planning, and distributed gas technologies. The search strategy used a combination of keywords and Boolean operators, including "off-grid gas-to-power", "geospatial energy planning", "distributed energy systems", "market intelligence", "energy access", "mini-grids", and "gas infrastructure deployment". Truncations and synonyms were also applied to ensure comprehensive coverage.

Inclusion criteria required that studies focus on the application of geospatial data, modeling techniques, or market intelligence tools to guide decision-making for off-grid or decentralized gas-to-power systems. Eligible studies included empirical analyses, simulation-based models, case studies, and policy-oriented reviews that explored spatial prioritization, infrastructure mapping, socio-economic targeting, or investment risk profiling. Exclusion criteria filtered out studies that addressed unrelated energy technologies, did not incorporate spatial or market-based approaches, or were limited to purely theoretical frameworks without applied relevance.

The PRISMA process followed four key stages: identification, screening, eligibility, and inclusion. The identification phase produced 578 records. After removing duplicates, 429 studies were screened based on titles and abstracts. Of these, 154 full-text articles were assessed for eligibility, and 63 studies were included in the final synthesis. Snowball sampling of citations and reference lists was used to identify additional relevant sources, especially from key organizations such as the International Energy Agency (IEA), Sustainable Energy for All (SE4All), and the World Bank.

Data extraction and synthesis focused on extracting information regarding geographic context, spatial modeling approaches, gas infrastructure planning, demand estimation methods, policy frameworks, and tools used for market analysis. Key themes emerged, including the use of satellite imagery and GIS-based optimization for site selection, integration of demographic and income data to map energy demand, and applications of remote sensing to assess infrastructure proximity and logistics. Studies also evaluated the role of market intelligence in understanding consumer preferences, price sensitivity, and regulatory readiness, enabling better targeting of private sector-led deployments.

Quality assessment was conducted using adapted criteria based on methodological rigor, transparency in data sources, scalability of models, and relevance to real-world gas-to-power planning. High-quality studies clearly articulated their assumptions, validated their spatial models against real deployment data, and considered institutional and socio-political variables in decision-making. Limitations in data availability, model resolution, and uncertainty quantification were also noted and considered in the synthesis.

The systematic review confirms that geospatial and market intelligence approaches significantly enhance the effectiveness of off-grid gas-to-power deployment strategies by enabling data-driven site prioritization, minimizing delivery costs, and improving investor confidence. The PRISMA methodology ensured a structured, transparent, and replicable process for identifying best practices and actionable insights, laying the groundwork for future applied research and implementation efforts in energy-deprived regions.

2.1 Off-Grid Gas-to-Power: Opportunities and Challenges

Off-grid gas-to-power systems present a promising solution to the persistent energy access challenges in underserved and remote regions. By harnessing natural gas through distributed technologies such as small-scale liquefied natural gas (LNG), compressed natural gas (CNG), microturbines, and gas generators, these systems offer a viable alternative to conventional grid extension and diesel-based generation (Olajide *et al*., 2020; Akinbola *et al*., 2020). As global efforts to achieve universal access to electricity intensify, particularly in sub-Saharan Africa, South Asia, and parts of Latin America, off-grid gas-to-power solutions are gaining attention for their capacity to deliver cleaner, more reliable, and scalable power where traditional infrastructure is economically or logistically unfeasible.

Gas-to-power technologies for off-grid use vary in scale and complexity. Small-scale LNG and CNG systems serve as key enablers of decentralized gas distribution. These systems typically involve the liquefaction or compression of natural gas at a central facility, followed by transportation via truck or skid-mounted containers to end-use locations. Once delivered, regasification units convert the LNG or CNG back into a gaseous state for combustion in power generation units. Microturbines and gas-fired generators then utilize the gas to produce electricity, often in modular and containerized formats suitable for rapid deployment. Microturbines, in particular, offer high efficiency and low emissions, and are suitable for continuous or peak load applications. Gas generators, available in capacities ranging from a few kilowatts to several megawatts, provide flexible, responsive power for both residential clusters and commercial users (Molina, 2017; Duffy *et al*., 2018).

In off-grid and underserved regions, these technologies offer significant benefits. First, they improve energy reliability and resilience in areas prone to blackouts, grid instability, or climatic disruptions. Gas systems are less susceptible to supply chain disruptions than diesel fuel, and LNG/CNG storage enables energy availability even in remote locations. Second, gas-to-power is cleaner than diesel, emitting fewer particulates, sulfur oxides, and greenhouse gases. This contributes to improved air quality and aligns with decarbonization goals, particularly in communities that depend on diesel generators with high environmental and health impacts. Third, gas generators and microturbines typically require less maintenance and have longer operational life spans, reducing long-term costs. Finally, gas systems can be hybridized with renewables like solar and battery storage to further enhance sustainability and reduce fuel dependency, making them critical assets in integrated energy planning (Eriksson and Gray, 2017; Safari *et al*., 2019).

Despite these advantages, off-grid gas-to-power systems face considerable technical, financial, and regulatory challenges. From a technical perspective, transporting LNG or CNG to remote locations requires specialized logistics and infrastructure, including cryogenic tanks, regasification units, and trained personnel. The lack of standardized designs for modular gas units also limits scalability. Moreover, supply reliability depends on the proximity of gas feedstock and the resilience of upstream supply chains, which can be compromised in politically unstable or infrastructure-poor regions. Financially, high upfront capital expenditure is a barrier, particularly in low-income or unbanked areas. Investment in distribution networks, power units, and supporting facilities can be prohibitive without concessional financing, guarantees, or blended finance mechanisms (Weston *et al*., 2018; Pories *et al*., 2019). Furthermore, irregular or low revenue streams from end-users, especially in rural communities, discourage private sector participation without targeted subsidies or demand aggregation mechanisms.

Regulatory barriers also impede growth. Many countries lack clear frameworks for licensing, tariff setting, and safety standards for off-grid gas systems. Ambiguities in land access rights, fuel pricing mechanisms, and environmental regulations further deter investors. The absence of coordinated policy support and institutional capacity to oversee gas distribution for power purposes often results in project delays, cost overruns, or operational inefficiencies. Additionally, international development finance institutions have historically focused more on renewable energy and large-scale infrastructure, limiting the availability of funding and technical assistance for gas-based mini-grids and decentralized systems (Schwerhoff and Sy, 2017; Clark *et al*., 2018).

Given these constraints, the importance of targeted, data-driven deployment strategies cannot be overstated. Effective planning requires the integration of geospatial data, demographic indicators, and market intelligence to identify viable sites, optimize logistics, and match supply with latent demand. High-resolution mapping of population density, existing infrastructure, income levels, and commercial activity can inform the prioritization of deployment zones. Data on local fuel prices, logistics corridors, and energy use patterns can improve financial modeling and risk assessment. Moreover, stakeholder engagement, including community consultation and government coordination, is essential to align project design with local needs and regulatory requirements. Digital tools, such as remote sensing and AI-powered analytics, enhance the precision and efficiency of these assessments, thereby increasing the likelihood of project success and scalability (Ossai and Oliha, 2019; Mohammadpour *et al*., 2019).

Off-grid gas-to-power technologies represent a strategic opportunity to expand energy access in regions where grid extension is not viable or economically justified. While these systems offer clear advantages in terms of reliability, environmental performance, and operational flexibility, their deployment is hindered by technical, financial, and regulatory constraints (Bonilla *et al*., 2018; Fores, 2019). A shift toward data-informed, strategically targeted interventions—supported by robust policy frameworks and innovative financing mechanisms—is essential to overcome these barriers and unlock the full potential of decentralized gas-to-power systems in driving sustainable energy access.

2.2 Geospatial Planning for Energy Deployment

Geospatial planning, driven by Geographic Information Systems (GIS), has emerged as an indispensable tool in modern energy deployment strategies, particularly for decentralized and off-grid applications. In the context of gas-to-power systems, GIS enables energy planners, policymakers, and private sector actors to identify high-impact locations for infrastructure investments by integrating spatial, demographic, and economic data (Dorgbefu, 2018; Jacquot *et al*., 2019). This data-centric approach enhances decision-making accuracy, reduces project development time, and ensures optimal allocation of resources in areas where energy needs are greatest and conventional grid extension is infeasible.

The role of GIS in identifying suitable sites for off-grid gas-to-power deployment lies in its ability to layer multiple geospatial datasets to reveal intersections of need, opportunity, and feasibility. By analyzing spatial relationships between energy demand, infrastructure availability, and geographic constraints, GIS models can pinpoint clusters of underserved or unserved communities and industries that are both technically accessible and economically viable for gas-based electrification. Furthermore, GIS facilitates scenario modeling, enabling planners to compare different deployment options and forecast outcomes based on varying infrastructure and demographic assumptions (Pettit *et al*., 2018; Goodspeed and Hackel, 2019).

Several key datasets are crucial for effective geospatial energy planning. First, population density maps help to locate rural and peri-urban areas with sufficient consumer bases to justify off-grid generation. These datasets, often derived from satellite imagery or census data, are essential for understanding the scale of local demand. Second, existing infrastructure layers—including roads, transmission lines, substations, and distribution networks—inform the logistical and operational feasibility of project deployment. Third, industrial and commercial activity maps identify areas where concentrated economic activity, such as mining, agro-processing, or manufacturing, could anchor a reliable demand for gas-to-power solutions. Fourth, distance to gas supply infrastructure, such as LNG import terminals, CNG depots, and pipeline networks, is a critical determinant of fuel delivery cost and reliability. Additional data layers, such as terrain elevation, environmental constraints, and land-use classifications, can further refine site selection by identifying areas that are physically accessible and environmentally permissible for development.

GIS-based tools also allow for comprehensive mapping of energy demand and infrastructure gaps. These tools integrate national electrification data with remote sensing inputs to determine which areas lack grid access, suffer from unreliable supply, or depend heavily on polluting energy sources like diesel. By linking this demand data with socio-economic indicators—such as income levels, education rates, and business activity—planners can develop multi-dimensional energy access indices to prioritize high-impact areas for intervention (Papageorgiou *et al*., 2019; Sinha, 2019). This form of geospatial energy equity mapping ensures that deployment strategies are not only economically rational but also socially inclusive.

There are several compelling case examples demonstrating the power of GIS in energy planning. In Nigeria, the Rural Electrification Agency (REA), in collaboration with the Rocky Mountain Institute, developed the Nigeria Energy Access Geospatial Platform. This tool maps over 200,000 settlements across the country, providing detailed insights into population density, grid proximity, and energy demand profiles. It has been instrumental in guiding the placement of mini-grids and off-grid solar systems and can be similarly adapted for gas-to-power planning. In India, the Smart Power India initiative uses GIS to identify rural commercial loads and design distributed energy systems that align with economic development hubs. In East Africa, Power Africa's GIS-based platform has enabled the identification of productive use zones near agriculture corridors and border towns, facilitating targeted investments in clean and reliable power systems.

Geospatial planning through GIS is a cornerstone of modern off-grid energy deployment, offering a powerful means to align infrastructure development with real-world conditions and needs. For gas-to-power systems, GIS not only informs where to deploy resources but also provides a foundation for evaluating project viability and impact. As more high-resolution spatial data and machine learning algorithms become available, GIS will continue to evolve as a dynamic decision-support tool, helping governments and developers deploy energy infrastructure more strategically, inclusively, and efficiently in underserved regions (Adamala, 2017; Sun and Scanlon, 2019).

2.3 Market Intelligence Integration

The integration of market intelligence into the planning and deployment of off-grid gas-to-power systems is essential for ensuring commercial viability, effective resource allocation, and sustainable impact. Market intelligence, in this context, refers to the systematic collection, analysis, and application of data related to energy demand, customer behavior, economic activity, and the broader regulatory and demographic environment as shown in figure 1(Tahmasebifard, 2018; Gebhardt *et al*., 2019). By leveraging such insights, developers, investors, and policy-makers can more accurately target high-potential areas, design suitable energy solutions, and mitigate market entry risks.

A critical component of market intelligence is the detailed understanding of local energy demand profiles and customer segments. Energy demand in off-grid or underserved areas is not homogenous; it varies by household income, commercial activity, time of day, and seasonality. Collecting granular data on consumption patterns enables planners to segment customers into distinct groups such as residential users, small businesses, agricultural processors, and institutional consumers (e.g., schools, clinics). Each segment has different load profiles, reliability needs, and sensitivity to energy costs. For example, residential users may require electricity primarily for lighting and refrigeration, while agricultural cooperatives may have high-power demands for irrigation or processing equipment. Understanding these variations allows developers to right-size generation and distribution assets, design tailored tariff structures, and plan demand-side management strategies that improve load balancing and system efficiency (Bell *et al*., 2018; Nowak *et al*., 2019).

Closely linked to demand profiling is the mapping of local economic activity, particularly in identifying key industrial, agricultural, and commercial nodes. These economic clusters often act as energy anchors that can enhance the financial viability of off-grid gas-to-power systems by providing a steady and relatively high demand for electricity. For instance, agro-processing centers, textile mills, cold storage facilities, and fisheries can serve as priority customers in rural areas, creating predictable revenue streams that justify infrastructure investment. Geographic Information Systems (GIS) and remote sensing tools are increasingly used to spatially map these nodes, incorporating data such as market sizes, transportation routes, and resource availability. By aligning energy deployment with existing or emerging economic zones, developers can enhance local productivity and catalyze broader socioeconomic development (Cloke *et al*., 2017; Narula and Zhan, 2019).

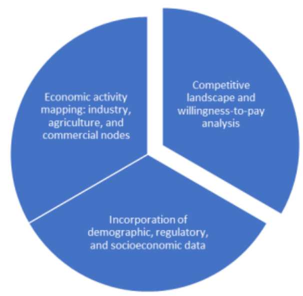

Figure 1: Market Intelligence Integration

Another critical pillar of market intelligence is the assessment of the competitive landscape and willingness-to-pay (WTP) analysis. Understanding the presence and pricing strategies of alternative energy sources, such as diesel generators, solar home systems, or grid extensions, helps in evaluating the market potential and positioning of gas-to-power solutions. For example, in regions where diesel is the dominant energy source and costs are high, gas-based solutions can be marketed as cleaner and more affordable alternatives. Conversely, in areas with heavily subsidized electricity tariffs, off-grid developers may face challenges in competing on price. WTP analysis involves surveys and field studies to determine how much different customer segments are willing and able to pay for reliable electricity services. This information is critical for designing tiered tariff models, selecting financing mechanisms, and assessing project bankability. Additionally, behavioral insights from WTP studies can inform marketing and customer education campaigns, helping to build trust and accelerate adoption (Chica and Rand, 2017; Haq and Weiss, 2018).

Equally important is the incorporation of demographic, regulatory, and socioeconomic data into the market intelligence framework. Demographic indicators such as population density, household size, education levels, and migration patterns provide context for estimating current and future energy demand. For instance, fast-growing peri-urban areas may present rising demand that supports scalable energy infrastructure, while aging rural populations may require smaller, decentralized systems with lower growth projections. Socioeconomic data, including income distribution, employment patterns, and access to finance, further refine the demand assessment and help in identifying customers most in need of flexible payment models or subsidies. Regulatory analysis is also vital; it includes evaluating the legal environment for energy licensing, fuel transport, environmental compliance, and land use (Sam *et al*., 2019; Karim *et al*., 2019). Understanding policy incentives, tariff regulations, and market liberalization trends enables developers to navigate bureaucratic hurdles and align with national electrification goals.

The synthesis of these diverse data sources through advanced analytics platforms, AI models, and GIS visualization tools allows stakeholders to generate dynamic market maps that guide investment decisions. These tools can identify clusters with high potential energy demand, low service coverage, favorable policy environments, and economically active populations. They also support scenario modeling, helping planners evaluate the impact of different pricing strategies, fuel supply constraints, or regulatory changes on project outcomes. Furthermore, market intelligence integration facilitates stakeholder coordination by providing a shared evidence base for governments, private investors, NGOs, and donors to align their interventions and avoid duplication of efforts.

Market intelligence integration is not merely a technical exercise but a strategic enabler of successful off-grid gas-to-power deployment. By systematically understanding local energy demand, mapping economic activities, assessing customer willingness to pay, and analyzing demographic and regulatory conditions, stakeholders can reduce risks, optimize returns, and ensure that energy solutions are responsive to real-world needs. As the global energy transition emphasizes inclusivity and sustainability, data-driven decision-making rooted in robust market intelligence will be indispensable for unlocking the transformative potential of decentralized gas-to-power systems (Lepri *et al*., 2017; Olayinka, 2019).

2.4 Conceptual Framework for Integration

An integrated planning approach that merges Geographic Information Systems (GIS) with market intelligence offers a powerful framework for accelerating off-grid gas-to-power deployment in emerging economies. The complexity and capital intensity of gas infrastructure—combined with the fragmented nature of data in many developing regions—require a structured, data-driven methodology to reduce project risk, enhance targeting accuracy, and maximize socio-economic impact as shown in figure 2(Jain *et al*., 2017; Daher *et al*., 2017). The proposed conceptual framework consists of a layered architecture that synthesizes geospatial, economic, regulatory, and technical datasets within a digital planning platform, enabled by artificial intelligence (AI) and machine learning (ML) tools to optimize decision-making throughout the project lifecycle.

At the core of this framework is a three-tier architecture designed to facilitate the seamless interaction of multiple data dimensions. The first tier is the *geospatial layer*, powered by GIS technology, which captures physical and demographic data such as population distribution, proximity to gas pipelines or depots, topography, land use, and accessibility. The second tier consists of *market intelligence*, which includes customer segmentation, demand forecasting, economic activity mapping, energy usage profiles, and willingness-to-pay metrics (Dutta and Mitra, 2017; Guo *et al*., 2019). The third tier is a *regulatory and technical feasibility layer*, integrating information on environmental constraints, land ownership, permitting requirements, and gas infrastructure availability (e.g., LNG terminals, road access for CNG delivery, or mini-pipeline networks). These tiers form the backbone of the integrated platform, feeding into a centralized decision-support environment for planning and execution.

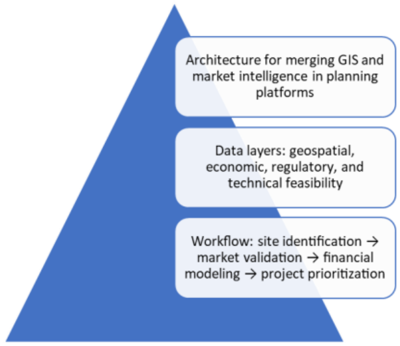

Figure 2: Conceptual Framework for Integration

Each of these layers contributes to a systematic workflow that guides planners through the four key stages of project development: site identification, market validation, financial modeling, and project prioritization. In the site identification phase, GIS tools are used to overlay population clusters with low electrification rates, proximity to gas logistics infrastructure, and areas with high potential energy demand—such as agricultural processing zones or industrial parks. Market validation follows, wherein socio-economic and energy consumption data are analyzed to assess the demand characteristics, customer types, and potential anchor loads. This step evaluates economic viability through data such as income distribution, electricity tariffs, and fuel substitution costs (e.g., switching from diesel to gas).

Subsequently, financial modeling integrates site-specific technical data with market assumptions to simulate capital expenditures, operating costs, revenue projections, and return on investment. This process includes sensitivity analyses to test financial outcomes under various risk scenarios, such as fuel price volatility or customer default rates. The final stage, project prioritization, involves ranking sites based on multi-criteria analysis—balancing economic, social, and environmental metrics—to guide developers and policymakers in selecting the most impactful and bankable projects for implementation.

AI and machine learning play a critical role in enhancing the intelligence and adaptability of this framework. Machine learning algorithms can be trained on historical energy access projects to identify success factors, predict customer adoption rates, and estimate demand elasticity. These algorithms can also process satellite imagery to refine settlement detection and identify informal settlements not captured in traditional census data. Predictive models enable planners to anticipate shifts in energy demand, infrastructure degradation, or changes in regional economic activity that could influence the long-term viability of a project (Debnath and Mourshed, 2018; Govindan and Al-Ansari, 2019). Natural language processing (NLP) tools may also be integrated to analyze regulatory texts, social media feedback, or customer surveys, thereby adding qualitative insights to the planning process.

By embedding AI/ML into the platform, the framework becomes adaptive—continuously learning from project outcomes, refining assumptions, and improving the accuracy of future site assessments. Moreover, automation features can streamline the generation of feasibility reports, geospatial dashboards, and investment briefs, reducing the administrative burden on planning teams and accelerating project timelines.

The integration of GIS and market intelligence within a unified, AI-enabled planning framework provides a robust foundation for scalable and data-driven off-grid gas-to-power deployment. This approach not only enhances spatial targeting and financial viability but also supports policy coherence and investment mobilization by offering a transparent, evidence-based methodology. As energy access challenges evolve, such integrated frameworks will be essential for deploying resources efficiently and equitably in underserved regions.

2.5 Case Studies and Applications

Case studies from countries such as Nigeria, Mozambique, and Indonesia provide valuable insights into the practical application of off-grid gas-to-power systems and the role of geospatial and market intelligence in enhancing project outcomes. These examples demonstrate how tailored approaches, informed by local data and contextual understanding, can significantly improve energy access, investment efficiency, and system scalability in underserved regions.

In Nigeria, the integration of compressed natural gas (CNG) and small-scale liquefied natural gas (LNG) into decentralized energy systems has shown promise, especially in the industrial corridors of the southwest and the agricultural hubs of the Middle Belt. The Nigerian Gas Expansion Programme (NGEP) and the Nigerian Gas Flare Commercialization Programme (NGFCP) have encouraged private sector involvement in capturing flared gas and repurposing it for power generation. In several pilot projects, geospatial mapping of flare sites, local economic activity, and energy demand clusters has allowed for more effective targeting of high-impact areas. For instance, a gas-to-power project in Ogun State used demand forecasting and demographic data to identify agro-processing clusters as anchor loads, ensuring steady demand and reducing revenue risk. The results included improved electricity reliability, reduced diesel dependence, and increased productivity for local industries, showcasing how localized planning can drive investment efficiency and social impact (Cox *et al*., 2017; Booth *et al*., 2017).

Mozambique presents another compelling example, particularly in the provinces of Inhambane and Cabo Delgado, where significant natural gas reserves coexist with large off-grid populations. Leveraging donor-supported energy mapping tools, the Mozambican government identified rural towns with potential for mini-grids powered by gas microturbines. These sites were selected based on demographic data, distance from the central grid, local economic activity (such as fisheries and small manufacturing), and ease of gas logistics. Public-private partnerships helped deploy modular gas systems that now power health clinics, schools, and small enterprises. The World Bank's support through technical assistance and blended finance mechanisms facilitated risk reduction and encouraged private sector participation. A key lesson from Mozambique is the importance of clear regulatory pathways and local stakeholder engagement, which helped align community expectations with project goals and fostered long-term sustainability.

Indonesia's archipelagic geography has made centralized electrification challenging, but gas-to-power technologies have proven effective in bridging energy access gaps. On islands such as Sumatra and Sulawesi, state-owned Pertamina and its subsidiaries have piloted small-scale LNG distribution networks linked to mini-grids serving off-grid communities. These projects incorporated spatial analytics to identify villages with high unmet demand, proximity to LNG terminals, and economic potential. The integration of socioeconomic data and willingness-to-pay studies allowed developers to tailor tariff structures, reducing the risk of non-payment and enhancing customer acceptance. Importantly, Indonesia's experience demonstrates the scalability of modular gas systems when supported by national infrastructure planning and cross-sectoral coordination. The alignment of transport, energy, and economic development strategies proved critical in reducing deployment costs and accelerating project replication.

Across these case studies, several common lessons emerge. First, geospatial and market intelligence are indispensable for identifying commercially viable and socially impactful deployment zones. Second, investment efficiency is enhanced when projects are designed around anchor loads and integrated with existing or planned infrastructure. Third, success depends on multi-stakeholder collaboration, including government support, private investment, and community participation. Finally, scalability is achievable when systems are modular, regulatory frameworks are clear, and financial mechanisms are in place to support both capital and operational expenditures (Hinker *et al*., 2018; Zachariadis *et al*., 2019).

The experiences of Nigeria, Mozambique, and Indonesia highlight the transformative potential of off-grid gas-to-power systems when guided by data-driven planning and local contextualization. These case studies offer replicable models for other countries facing similar electrification challenges, demonstrating that with the right intelligence, infrastructure, and incentives, decentralized gas solutions can be a critical pathway toward universal energy access.

2.6 Strategic Implications and Policy Recommendations

The integration of geospatial planning and market intelligence into off-grid gas-to-power deployment presents profound strategic implications for energy access, economic development, and investment mobilization in emerging economies. As global energy markets evolve toward decentralization and low-carbon solutions, off-grid gas systems—especially those powered by compressed natural gas (CNG) or liquefied natural gas (LNG)—offer scalable, reliable, and cleaner alternatives to diesel generators in underserved regions. To unlock their full potential, however, it is imperative to address structural barriers to investment, coordination, and implementation as shown in figure 3. A robust strategy built around de-risked investment targeting, supportive policy environments, and coordinated partnerships is central to catalyzing sustainable scale (Oliver *et al*., 2018; Rowden, 2019).

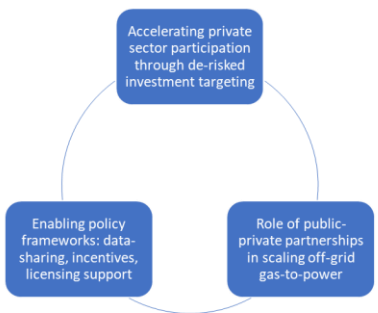

Figure 3: Strategic Implications

One of the most important strategic outcomes of this integrated approach is its ability to accelerate private sector participation by lowering entry risks. Gas-to-power projects are typically capital-intensive and location-sensitive, requiring careful alignment between infrastructure availability, demand certainty, and regulatory stability. The use of GIS-based site identification and market intelligence enables developers and financiers to pinpoint high-potential locations with verified customer demand, logistical feasibility, and proximity to fuel supply. This reduces project uncertainty, shortens due diligence timelines, and increases the bankability of investments. Furthermore, by incorporating predictive analytics, developers can better estimate customer uptake and revenue potential, allowing for more accurate financial modeling and risk mitigation. This data-driven clarity is particularly valuable in markets where trust in energy demand forecasting is weak or where past projects have suffered from poor siting and planning.

In tandem with better data and tools, governments must develop enabling policy frameworks to support streamlined deployment. Key measures include standardized licensing procedures for small-scale gas and power generation, coordinated permitting processes that reduce administrative bottlenecks, and fiscal incentives—such as tax holidays or duty exemptions on imported equipment—to improve project economics. Data-sharing mandates are also critical: energy ministries, utilities, and regulatory agencies should be required to make geospatial and infrastructure datasets publicly available to ensure consistent, high-quality inputs for site selection. Moreover, policies that support open access to gas infrastructure—such as pipelines, LNG terminals, and CNG stations—can help unlock broader geographic coverage for decentralized gas delivery.

To achieve sustainable and inclusive scale, the role of public-private partnerships (PPPs) is indispensable. Governments can leverage PPPs to co-develop projects, co-finance distribution infrastructure, or aggregate demand across anchor institutions (e.g., agro-processing centers, hospitals, schools) to create stable revenue bases. By sharing risks and coordinating investments, PPPs can lower the capital burden on private developers while expanding service coverage to economically marginal but socially critical areas (Ahmad *et al*., 2017; Liu *et al*., 2017). Multilateral development banks (MDBs) and bilateral donors can support these partnerships by providing blended finance instruments, such as concessional loans or first-loss guarantees, which enhance creditworthiness and encourage local capital market participation.

Based on the strategic analysis above, the following recommendations are proposed for key stakeholders; Governments should establish integrated national planning platforms that combine GIS, market data, and regulatory tracking, and mandate the use of such tools for energy infrastructure siting. They should also create regulatory sandboxes for testing innovative off-grid business models, and develop clear legal definitions for small-scale gas-to-power systems. Donors and development partners should fund the development and maintenance of open-access geospatial and demand databases, support capacity-building programs for local planners, and provide de-risking instruments to crowd in private investment. Developers and private investors should incorporate geospatial planning into their early-stage feasibility assessments, use AI and data analytics to refine demand projections, and pursue partnerships with public institutions and local enterprises to aggregate demand and share logistics.

Deploying off-grid gas-to-power solutions at scale requires more than technical innovation; it demands integrated planning, enabling policies, and coordinated action across public and private sectors. The strategic use of geospatial and market intelligence not only improves deployment efficiency but also builds investor confidence, enhances regulatory transparency, and ultimately accelerates the transition to a more resilient, inclusive, and sustainable energy future in emerging economies.

CONCLUSION AND FUTURE DIRECTIONS

The integration of geospatial planning and market intelligence in off-grid gas-to-power deployment represents a significant advancement in the strategic expansion of energy access. By combining spatial analytics, demographic profiling, and economic insights, stakeholders can more accurately identify high-impact deployment zones, optimize infrastructure investments, and tailor energy solutions to the needs and capacities of underserved communities. This data-driven approach enhances decision-making at every level—from policy formulation to project design and private sector engagement—ultimately increasing the likelihood of technical, financial, and social success. Notably, geospatial and market-informed planning allows for better alignment between energy supply and local demand, facilitates the identification of anchor loads, and supports the efficient allocation of limited financial and natural resources. These benefits are especially vital in resource-constrained environments where electrification efforts must be targeted, cost-effective, and inclusive.

Despite the progress made, there remains an urgent need for the development of integrated digital energy access platforms that can bring together disparate data sources, modeling tools, and stakeholder functions into cohesive ecosystems. Such platforms would enable real-time analysis of energy demand, supply logistics, and regulatory environments while promoting interoperability between actors across the energy value chain. By aggregating and visualizing spatial, economic, demographic, and technical data, these platforms can serve as central planning tools for governments, developers, and financiers. Moreover, digital platforms would facilitate scenario modeling and impact assessment, supporting adaptive planning and rapid response to changing conditions such as fuel price shifts, climate impacts, or population movements. The incorporation of user-friendly dashboards and open-access interfaces can further democratize access to energy intelligence, empowering local governments and communities to actively participate in planning and decision-making processes.

Looking ahead, several future research directions are critical to advancing the field. First, there is a need for improved dynamic demand modeling that captures temporal and behavioral variations in energy use. Existing models often assume static or average load profiles, which can lead to over- or under-sizing of systems. Enhanced models that integrate time-of-use data, appliance ownership, economic activity cycles, and seasonal variation would enable more precise demand forecasting and system design. Second, the use of remote sensing and Earth observation technologies offers immense potential for expanding the scope and resolution of energy planning. High-resolution satellite imagery, combined with machine learning algorithms, can detect built infrastructure, assess energy poverty indicators, and monitor land-use changes in near real time. These capabilities can be particularly valuable in inaccessible or conflict-prone areas where on-the-ground surveys are difficult. Third, the application of blockchain technology in energy mapping and governance presents a novel frontier. Blockchain can support decentralized data validation, secure transaction recording, and transparent monitoring of energy access projects. For example, blockchain-based smart contracts could facilitate performance-based financing, track energy flows, and enforce compliance in distributed energy systems.

Geospatial and market intelligence approaches are revolutionizing the planning and deployment of off-grid gas-to-power systems. The adoption of integrated digital platforms and the advancement of emerging technologies such as dynamic modeling, remote sensing, and blockchain can significantly enhance the efficiency, transparency, and adaptability of energy access initiatives. As the global community strives toward universal electrification, sustained investment in research, data infrastructure, and collaborative innovation will be essential to fully unlock the potential of decentralized, data-informed energy systems.

REFERENCES

[1] Adamala, S., 2017. An overview of big data applications in water resources engineering. *Mach. Learn. Res*, *2*(1), pp.10-18.

[2] Ahmad, E., Bhattacharya, A., Vinella, A. and Xiao, K., 2017. Involving the private sector and PPPs in financing public investments: Some opportunities and challenges. *Fiscal Underpinnings for Sustainable Development in China: Rebalancing in Guangdong*, pp.123-159.

[3] Ajonbadi, H.A., Otokiti, B.O. and Adebayo, P., 2016. The efficacy of planning on organisational performance in the Nigeria SMEs. *European Journal of Business and Management*, *24*(3), pp.25-47.

[4] AjonbadiAdeniyi, H., AboabaMojeed-Sanni, B. and Otokiti, B.O., 2015. Sustaining competitive advantage in medium-sized enterprises (MEs) through employee social interaction and helping behaviours. *Journal of Small Business and Entrepreneurship*, *3*(2), pp.1-16.

[5] Akinbola, O.A. and Otokiti, B.O., 2012. Effects of lease options as a source of finance on profitability performance of small and medium enterprises (SMEs) in Lagos State, Nigeria. *International Journal of Economic Development Research and Investment*, *3*(3), pp.70-76.

[6] Akinbola, O.A., Otokiti, B.O., Akinbola, O.S. and Sanni, S.A., 2020. Nexus of born global entrepreneurship firms and economic development in Nigeria. *Ekonomicko-manazerske spektrum*, *14*(1), pp.52-64.

[7] Amos, A.O., Adeniyi, A.O. and Oluwatosin, O.B., 2014. Market based capabilities and results: inference for telecommunication service businesses in Nigeria. *European Scientific Journal*, *10*(7).

[8] Bell, K., Gross, R. and Watson, J., 2018. Ofgem RIIO-2 Consultation: Response from the UK Energy Research Centre (UKERC).

[9] Bonilla, S.H., Silva, H.R., Terra da Silva, M., Franco Gonçalves, R. and Sacomano, J.B., 2018. Industry 4.0 and sustainability implications: A scenario-based analysis of the impacts and challenges. *Sustainability*, *10*(10), p.3740.

[10] Booth, S., Li, X., Baring-Gould, I., Kollanyi, D., Bharadwaj, A. and Weston, P., 2018. *Productive use of energy in African micro-grids: Technical and business considerations* (No. NREL/TP-7A40-71663). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[11] Chica, M. and Rand, W., 2017. Building agent-based decision support systems for word-of-mouth programs: A freemium application. *Journal of Marketing Research*, *54*(5), pp.752-767.

[12] Clark, R., Reed, J. and Sunderland, T., 2018. Bridging funding gaps for climate and sustainable development: Pitfalls, progress and potential of private finance. *Land use policy*, *71*, pp.335-346.

[13] Cloke, J., Mohr, A. and Brown, E., 2017. Imagining renewable energy: Towards a Social Energy Systems approach to community renewable energy projects in the Global South. *Energy research & social science*, *31*, pp.263-272.

[14] Cox, S.L., Hotchkiss, E.L., Bilello, D.E., Watson, A.C. and Holm, A., 2017. *Bridging climate change resilience and mitigation in the electricity sector through renewable energy and energy efficiency: Emerging climate change and development topics for energy sector transformation* (No. NREL/TP-6A20-67040). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[15] Daher, E., Kubicki, S. and Guerriero, A., 2017. Data-driven development in the smart city: Generative design for refugee camps in Luxembourg. *Entrepreneurship and Sustainability Issues*, *4*(3), p.364.

[16] Debnath, K.B. and Mourshed, M., 2018. Challenges and gaps for energy planning models

in the developing-world context. *Nature Energy*, *3*(3), pp.172-184.

[17] Dorgbefu, E.A., 2018. Leveraging predictive analytics for real estate marketing to enhance investor decision-making and housing affordability outcomes. *Int J Eng Technol Res Manag*, *2*(12), p.135.

[18] Duffy, P., Fitzpatrick, C., Conway, T. and Lynch, R.P., 2018. Energy sources and supply grids–the growing need for storage.

[19] Dutta, G. and Mitra, K., 2017. A literature review on dynamic pricing of electricity. *Journal of the Operational Research Society*, *68*(10), pp.1131-1145.

[20] Eriksson, E.L.V. and Gray, E.M., 2017. Optimization and integration of hybrid renewable energy hydrogen fuel cell energy systems–A critical review. *Applied energy*, *202*, pp.348-364.

[21] FAGBORE, O.O., OGEAWUCHI, J.C., ILORI, O., ISIBOR, N.J., ODETUNDE, A. and ADEKUNLE, B.I., 2020. Developing a Conceptual Framework for Financial Data Validation in Private Equity Fund Operations.

[22] Fores, B., 2019. Beyond gathering the 'low-hanging fruit'of green technology for improved environmental performance: an empirical examination of the moderating effects of proactive environmental management and business strategies. *Sustainability*, *11*(22), p.6299.

[23] Gebhardt, G.F., Farrelly, F.J. and Conduit, J., 2019. Market intelligence dissemination practices. *Journal of marketing*, *83*(3), pp.72-90.

[24] Goodspeed, R. and Hackel, C., 2019. Lessons for developing a planning support system infrastructure: The case of Southern California's Scenario Planning Model. *Environment and Planning B: Urban Analytics and City Science*, *46*(4), pp.777-796.

[25] Govindan, R. and Al-Ansari, T., 2019. Computational decision framework for enhancing resilience of the energy, water and food nexus in risky environments. *Renewable and Sustainable Energy Reviews*, *112*, pp.653-668.

[26] Guo, B., Liu, Y., Ouyang, Y., Zheng, V.W., Zhang, D. and Yu, Z., 2019. Harnessing the power of the general public for crowdsourced business intelligence: a survey. *IEEE Access*, *7*, pp.26606-26630.

[27] Haq, G. and Weiss, M., 2018. Time preference and consumer discount rates-Insights for accelerating the adoption of efficient energy and transport technologies. *Technological Forecasting and Social Change*, *137*, pp.76-88.

[28] Hinker, J., Wohlfahrt, T., Drewing, E., Contreras Paredes, S.F., Mayorga González, D. and Myrzik, J.M., 2018. Adaptable energy systems integration by modular, standardized and scalable system architectures: necessities and prospects of any time transition. *Energies*, *11*(3), p.581.

[29] Jacquot, G., Pérez-Arriaga, I., Stoner, R.J. and Nagpal, D., 2019. Assessing the potential of electrification concessions for universal energy access: Towards integrated distribution frameworks.

[30] Jain, R.K., Qin, J. and Rajagopal, R., 2017. Data-driven planning of distributed energy resources amidst socio-technical complexities. *Nature Energy*, *2*(8), pp.1-11.

[31] Karim, M.E., Karim, R., Islam, M.T., Muhammad-Sukki, F., Bani, N.A. and Muhtazaruddin, M.N., 2019. Renewable energy for sustainable growth and development: An evaluation of law and policy of Bangladesh. *Sustainability*, *11*(20), p.5774.

[32] Lawal, A.A., Ajonbadi, H.A. and Otokiti, B.O., 2014. Leadership and organisational performance in the Nigeria small and medium enterprises (SMEs). *American Journal of Business, Economics and Management*, *2*(5), p.121.

[33] Lepri, B., Staiano, J., Sangokoya, D., Letouzé, E. and Oliver, N., 2017. The tyranny of data? The bright and dark sides of data-driven decision-making for social good. In *Transparent data mining for big and small data* (pp. 3-24). Cham: Springer International Publishing.

[34] Liu, T., Bennon, M., Garvin, M.J. and Wang, S., 2017. Sharing the big risk: Assessment framework for revenue risk sharing mechanisms

in transportation public-private partnerships. *Journal of Construction Engineering and Management*, *143*(12), p.04017086.

[35] Mohammadpour, A., Karan, E. and Asadi, S., 2019. Artificial intelligence techniques to support design and construction. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 36, pp. 1282-1289). IAARC Publications.

[36] Molina, M.G., 2017. Energy storage and power electronics technologies: A strong combination to empower the transformation to the smart grid. *Proceedings of the IEEE*, *105*(11), pp.2191-2219.

[37] Narula, R. and Zhan, J., 2019. Using special economic zones to facilitate development: policy implications. *Transnational Corporations Journal*, *26*(2).

[38] Nowak, S., Kushler, M. and Witte, P., 2019. The New Leaders of the Pack: ACEEE's Fourth National Review of Exemplary Energy Efficiency Programs.

[39] Nwani, S., Abiola-Adams, O., Otokiti, B.O. & Ogeawuchi, J.C., 2020. Building operational readiness assessment models for micro, small, and medium enterprises seeking government-backed financing. Journal of Frontiers in Multidisciplinary Research, 1(1), pp.38–43. Available at: https://doi.org/10.54660/.IJFMR.2020.1.1.38-43

[40] Olajide, J.O., Otokiti, B.O., Nwani, S., Ogunmokun, A.S., Adekunle, B.I., & Fiemotongha, J.E. (2020). Designing a financial planning framework for managing SLOB and write-off risk in fast-moving consumer goods (FMCG). IRE Journals, 4(4). https://irejournals.com/paper-details/1709016

[41] Olayinka, O.H., 2019. Leveraging predictive analytics and machine learning for strategic business decision-making and competitive advantage. *International Journal of Computer Applications Technology and Research*, *8*(12), pp.473-486.

[42] Oliver, P., Tonkonogy, B., Wang, D. and Wang, X., 2018. Supporting the momentum of Paris: a systems approach to accelerating climate finance. *Climate Policy Institute: London, UK*.

[43] Ossai, E.N. and Oliha, A.O., 2019. Integration of Geoinformatics and Artificial Intelligence: Enhancing Surveying Applications through Advanced Data Analysis and Decision-Making. *power*, p.17.

[44] Otokiti, B.O. and Akinbola, O.A., 2013. Effects of lease options on the organizational growth of small and medium enterprise (SME's) in Lagos State, Nigeria. *Asian Journal of Business and Management Sciences*, *3*(4), pp.1-12.

[45] Otokiti, B.O. and Akorede, A.F., 2018. Advancing sustainability through change and innovation: A co-evolutionary perspective. *Innovation: Taking creativity to the market. Book of Readings in Honour of Professor SO Otokiti*, *1*(1), pp.161-167.

[46] Otokiti, B.O., 2012. *Mode of entry of multinational corporation and their performance in the Nigeria market* (Doctoral dissertation, Covenant University).

[47] Otokiti, B.O., 2017. A study of management practices and organisational performance of selected MNCs in emerging market-A Case of Nigeria. *International Journal of Business and Management Invention*, *6*(6), pp.1-7.

[48] Otokiti, B.O., 2017. Social media and business growth of women entrepreneurs in Ilorin metropolis. *International Journal of Entrepreneurship, Business and Management*, *1*(2), pp.50-65.

[49] Papageorgiou, K., Singh, P.K., Papageorgiou, E., Chudasama, H., Bochtis, D. and Stamoulis, G., 2019. Fuzzy cognitive map-based sustainable socio-economic development planning for rural communities. *Sustainability*, *12*(1), p.305.

[50] Pettit, C., Bakelmun, A., Lieske, S.N., Glackin, S., Thomson, G., Shearer, H., Dia, H. and Newman, P., 2018. Planning support systems for smart cities. *City, culture and society*, *12*, pp.13-24.

[51] Pories, L., Fonseca, C. and Delmon, V., 2019. Mobilising finance for WASH: Getting the foundations right. *Water*, *11*(11), p.2425.

[52] Rowden, R., 2019. From the Washington consensus to the Wall Street consensus. *The financialization initiative of the World Bank and multilateral development banks*.

[53] Safari, A., Das, N., Langhelle, O., Roy, J. and Assadi, M., 2019. Natural gas: A transition fuel for sustainable energy system transformation?. *Energy Science & Engineering*, *7*(4), pp.1075-1094.

[54] Sam, K., Coulon, F. and Prpich, G., 2017. Management of petroleum hydrocarbon contaminated sites in Nigeria: Current challenges and future direction. *Land use policy*, *64*, pp.133-144.

[55] Schwerhoff, G. and Sy, M., 2017. Financing renewable energy in Africa–Key challenge of the sustainable development goals. *Renewable and Sustainable Energy Reviews*, *75*, pp.393-401.

[56] SHARMA, A., ADEKUNLE, B.I., OGEAWUCHI, J.C., ABAYOMI, A.A. and ONIFADE, O., 2019. IoT-enabled Predictive Maintenance for Mechanical Systems: Innovations in Real-time Monitoring and Operational Excellence.

[57] Sinha, B.R.K., 2019. Multidimensional approach to quality of life issues. *Institute of Science Banaras Hindu University Varanasi, Uttar Pradesh, India*.

[58] Sun, A.Y. and Scanlon, B.R., 2019. How can Big Data and machine learning benefit environment and water management: a survey of methods, applications, and future directions. *Environmental Research Letters*, *14*(7), p.073001.

[59] Tahmasebifard, H., 2018. The role of competitive intelligence and its sub-types on achieving market performance. *Cogent Business & Management*, *5*(1), p.1540073.

[60] Weston, P., Kalhoro, W., Lockhart, E., Reber, T.J. and Booth, S.S., 2018. *Financial and operational bundling strategies for sustainable micro-grid business models* (No. NREL/TP-7A40-72088). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[61] Zachariadis, M., Hileman, G. and Scott, S.V., 2019. Governance and control in distributed ledgers: Understanding the challenges facing blockchain technology in financial services. *Information and organization*, *29*(2), pp.105-117.