Nigerian Journal of Scientific Research (NJSR)
ISSN-0794-0378

ALIGNING ENERGY SECURITY AND SUSTAINABILITY: AN ASSESSMENT OF POTENTIAL HYBRID RENEWABLE ENERGY SYSTEMS (HRES) ADOPTION IN NIGERIAN AIRPORTS AND HANGARS

EMELU, C.C.[1], OKORHI, J.O.[2]*, UHUNMWANGHO, R.[3] AND BIG-ALABO, A.[3]
[1]Institute of Engineering, Technology & Innovation Management (METI), University of Port Harcourt, Nigeria, [2]Department of Environmental Management, Dennis Osadebay University, Asaba, Nigeria, [3]Electrical & Electronic Department, University of Port Harcourt, Nigeria

ABSTRACT
This study investigates the potential for aligning energy security and sustainability in Nigerian airports and hangars through the adoption of hybrid renewable energy systems (HRES). A questionnaire survey approach was used to investigate and assess the current state of energy use by 252 respondents in 12 selected airports across the 6 geopolitical zones, including primary energy sources, demand patterns, and stakeholder concerns. The quantitative results revealed a heavy reliance on diesel generators and the national grid, with a growing interest in solar PV systems. Peak energy demand occurs during daytime due to airport operations. Stakeholders identified financing limitations and insufficient government incentives as the biggest barriers to improving energy efficiency. A techno-economic framework was identified to explore the adoption of HRES. While cost savings might be achievable with HRES, more data is needed for confirmation. Stakeholders expressed concerns regarding the initial investment costs, reliability, and maintenance requirements of HRES. The study recommends a multi-pronged approach to facilitate HRES adoption. This includes establishing reliable financing mechanisms, providing capacity building on HRES operation and maintenance, and conducting feasibility studies at interested airports. By implementing the recommendations, Nigerian airports can enhance energy security, reduce reliance on fossil fuels, and contribute to a more sustainable aviation sector.

Keywords: Cost Savings, Energy Efficiency, Hybrid Renewable Energy Systems (HRES), Nigerian Airports, Renewable Energy Adoption
***Correspondence:** johnson.okorhi@dou.edu.ng, +234-813-789-1014

INTRODUCTION

The Nigerian aviation sector is a significant contributor to global energy consumption and greenhouse gas emissions. Its dependence on fossil fuel-based generators and grid electricity for powering infrastructure, facilities, mobility, etc. in airports and hangars hinders sustainable practices [1]. The heavy reliance on diesel generators and the national grid, susceptible to price fluctuations and supply disruptions with low energy access [2-4], raises concerns about energy security and environmental impacts [5, 6].

Hybrid Renewable Energy Systems (HRES) offer promising solutions by integrating renewable energy sources (RES) with conventional systems like generators and grid connections [3, 7, 8]. HRES can enhance energy security by reducing reliance on volatile fossil fuels and the national grid, while promoting sustainability by lowering greenhouse gas emissions and fostering a cleaner energy mix in Nigerian airports and hangars [1].

Therefore, this study aims to assess the current state of energy use and the potential for renewable energy (RE) adoption for HRES in Nigerian airports. It investigates two hypotheses: (a) $H_0 1$: "There is a potential for significant cost savings through the adoption of renewable energy in Nigeria airports", and (b) $H_0 2$: "Supportive government policies (incentives, regulations) and access to financing will significantly encourage the adoption of HRES in Nigeria airports." Limited research exists on the specific feasibility of HRES in this context. By addressing this gap, the study aims to inform stakeholders, policymakers, and investors about the potential benefits and challenges associated with HRES adoption in Nigerian airports and hangars.

The literature review on energy security and sustainability through hybrid renewable energy system (HRES) adoption aims to provide insights into current energy consumption patterns, identify inefficiencies, and highlight opportunities for improved energy utilization through renewable energy sources (RES). The adoption of hybrid renewable energy systems (HRES) in Nigerian airports and hangars can be understood through the lens of some complementary theories that follows: The Technology Acceptance Model (TAM) highlights the importance of stakeholders perceiving HRES as both useful (e.g., for cost savings and energy security) and easy to use (e.g., compatible with existing infrastructure) [9]. The Diffusion of Innovations Theory emphasizes the role of government incentives, financing mechanisms, and capacity building in facilitating the spread of HRES within the aviation sector [10]. Institutional Theory underscores the need for clear policies and regulations to create a supportive environment for HRES adoption [11]. Finally, Resource Dependence Theory suggests that airports and hangars are motivated to adopt HRES to reduce their reliance on the national grid and diesel generators, thereby enhancing their energy security and autonomy [12].

The aviation industry plays a crucial role in global socioeconomic development. Several studies highlight the rising energy demands of airports worldwide [13]. Orikpete *et al.* emphasized that air conditioning, lighting, and ground support equipment are major contributors to energy consumption in airports and hangars [6]. Additionally, due to the high speeds required for flight, air travel consumes a significant amount of energy, reflected in fuel costs, typically the second-highest expense for airlines (13-20% of their operational budget) [13].

Specific energy consumption patterns of Nigerian airports are not extensively documented. However, their reliance on diesel generators and a frequently disrupted national grid is well established [5, 14, 15]. The energy demand of the Nigerian aviation industry has garnered increased attention due to its implications for economic growth and environmental sustainability. As the industry expands and modernizes, a comprehensive analysis of energy demand within airports becomes paramount. Understanding current and future energy requirements will not only aid in effective resource management but also contribute to developing sustainable practices within the aviation sector. Addressing energy demand in this context is essential for aligning with global energy efficiency and carbon emission reduction goals. Therefore, a detailed examination of energy demand in Nigeria’s aviation industry, focusing on airports and hangars, is crucial for informing strategic energy management initiatives and promoting environmental responsibility.

A Hybrid Renewable Energy System (HRES) combines one or more renewable energy sources (solar, wind, hydro, etc.) with a conventional energy source (fuel cells, batteries, or diesel generators) to function as a stand-alone or grid-connected system [8]. According to Bajpai and Dash and Belgana *et al.*, a typical HRES block diagram showcases a combination of renewable energy sources working alongside backup devices [7, 16]. Stand-alone hybrid systems offer a significant advantage over single-source power generation, particularly in remote areas with limited electricity access. Their ability to combine multiple renewable sources enhances reliability. However, designing, controlling, and optimizing these hybrid systems can sometimes be complex [17].

Several studies demonstrate the potential of HRES to reduce energy costs, greenhouse gas emissions, and reliance on fossil fuels in airports and hangars [1, 7, 8, 18]. The integration of solar PV systems has successfully reduced daytime energy consumption in homes and public facilities. Battery storage can address concerns about grid dependence and ensure backup power during peak demand periods. Shaaban and Petinrin suggested that Nigeria has significant potential for renewable energy (RE) diversification [2]. The primary challenge lies in the nation’s limited technological capacity to effectively develop and utilize these renewable energy sources (RETs) [1]. Unlike single-source renewable energy systems reliant on one source like solar, wind, or hydro, hybrid renewable systems (HRES) combine two or more generation options as renewable energy technologies (RETs). The key advantage of HRES is their superior reliability. By combining sources, they are less susceptible to fluctuations in any single source. In addition, they often require less energy storage due to the complementary nature of different renewables (for instance, wind and solar often peak at different times). This improved efficiency and reduced storage requirement translate to lower overall costs when optimally designed [19].

Power outages and grid instability disrupt critical airport operations, jeopardizing safety, causing delays, and incurring economic losses [14]. These challenges necessitate exploring alternative energy solutions for airport facilities. A hybrid renewable energy system (HRES) offers a promising possibility. However, a comprehensive understanding of their design, economic feasibility, technicalities involved, and implementation considerations within the Nigerian context remains lacking [20-22]. Reports attribute this to the variability of renewable sources themselves, depending on location, and the lack of sufficient technical know-how for optimal design implementation.

There remain limited data on existing HRES installations in Nigerian airports and hangars hinder a comprehensive cost-benefit analysis. Current data on solar penetration is unreliable due to a lack of comprehensive records on installations [23-25]. This makes it difficult to assess the true extent of solar use in the country. While no solar energy currently feeds into the national grid, Sambo reported some isolated solar PV system installations totaling around 15 MW [26]. Estimates by Sambo and Bala suggest that dedicating just 1% of northern Nigerian land to solar power generation with 5% efficiency could produce a staggering 333,480 MW of electricity, highlighting the immense potential waiting to be harnessed [27]. Following an additional study by Ogbonnaya *et al.* [1], Nigeria has both high solar intensity and a wide range of wind speeds across different states, indicating the potential for harnessing energy from solar and wind sources. The study also pointed out that Nigeria's current electricity generation capacity is insufficient to meet the country's growing energy demands. In addition, it highlighted the potential for harnessing energy from other sources like biomass, geothermal, and hydro.

While technical factors emphasize renewable energy to electricity (RE2E) generation efficiency, technology maturity, and installed capacity, financial factors typically involve the investment cost, fixed and variable costs, operation and maintenance costs, and electricity costs of the RE2E generator. Financing limitations, lack of government incentives, concerns about initial costs, reliability, and maintenance were also identified as significant barriers to HRES adoption [4,14]. However, these authors identified public-private partnerships and innovative financing mechanisms (loans, grants) for HRES projects as a measure to address funding limitations in HRES adaptation for airports and hangars in Nigeria.

Solar energy is expected to be a major contributor to Nigeria's renewable energy mix, with a target of 15% by 2030. However, available data suggests the 2015 targets were not met [20]. Despite renewable energy opportunities, Nigeria's policy framework for RE includes a three-pronged approach: National Renewable Energy and Energy Efficiency Policy (NREEEP), Feed-in Tariff (FiT), and Multi-Year Tariff Order (MYTO) [23]. Newer sources suggest a broader framework with more than five policies, potentially incorporating tax breaks, FiTs, public funding, grants, and biofuel mandates [4, 23]. These policies were aimed to achieve ambitious RE targets, with a goal of 20% of electricity consumption coming from renewables by 2030. Government support through tax breaks, streamlined permitting processes, and feed-in tariffs can incentivize HRES adoption [4]. Financial instruments like loan and grant programs specifically designed for airport and hangar HRES projects can address financing limitations [23]. With appropriate policies in place, HRES offers Nigerian airports and hangars the potential for: Alternative/complementary power supply; Environmental sustainability; Economic benefits; Innovation, and; Development of a robust policy and regulatory framework for clean energy integration within the Nigerian aviation sector [2, 4, 6]. These authors also suggest that government policies offering feed-in tariffs or tax breaks for renewable energy projects can incentivize HRES adoption. Table 1 presents a summary of policy initiatives for renewable energy transition in Nigeria.

METHODOLOGY

Study area
The study area consisted of 12 Nigerian airports purposefully selected from over 26 airports managed by FAAN in the 6 Geopolitical Zones in Nigeria: North-West, North-East, North-Central, South-West, South-East, and South-South. Two airports (domestic and international) were selected from each of the 6 stratums.

Ethical clearance
Ethical clearance was obtained from the Federal Airport Authority (FAAN), Nigeria Civil Aviation Authority (NCAA), Nigerian Aviation Handling Company (NAHCO), Nigerian Airspace Management Agency (NAMA), Nigerian Meteorological Agency (NIMET) and other airport authorities.

Data sources and collection
Owing to the functionality and classification of Nigeria airports by FAAN, surveys were conducted with key stakeholders at purposively selected airports in the six geopolitical zones spreading evenly across twelve States in Nigeria. The respondents were HRES stakeholders in these 12 airports from the 12 strata of States. They were airport authorities, facility managers, engineering personnel and sustainability managers. This study employed an investigative method approach in collecting quantitative data from 252 respondents in the six mutually exclusive strata of geopolitical zones. Premised on categorization as domestic and international airports, climatic condition of the airport location, grid reliability, and passengers' traffic and usage, two airports were purposely selected from each stratum reflecting both domestic and international status. The surveys questions focused on current energy consumption patterns, existing energy-saving measures, perceptions of HRES, and potential challenges and opportunities for adoption.

Data analysis
The quantitative data collected from stakeholder surveys in this study underwent a rigorous analysis process to glean valuable insights into perceptions of HRES adoption in Nigerian airports and hangars. The descriptive and inferential statistics entailed the

use of frequency tables and percentages, measures of central tendency (mean, median), measures of dispersion (standard deviation, range), cross-tabulation, and statistical significance testing.

RESULTS AND DISCUSSION

Current energy use and renewable energy potential in Nigerian Airports

This section summarizes the findings on current energy use and the potential for renewable energy (RE) adoption in Nigerian airports. The survey achieved a high response rate (94.44%), with 238 completed and valid questionnaires received from senior officials in airport operations, facilities management, engineering, sustainability departments, and all other areas related to energy management in Nigerian airports.

The data is presented with Tables [A1 and B1] and Figures [A1-A5; B1-B4] to answer these questions: What is the current state of energy use and the potential for renewable energy adoption in Nigerian airports?; What policy and economic frameworks are necessary to facilitate the adoption of Hybrid Renewable Energy Systems (HRES) in Nigerian airports?

The survey data is then discussed in two parts: “Energy Sources, Demand, Usage and Options in Nigeria Airports and Hangars”, and “Techno-Economic Framework for HRES in Airports and Hangars”. Following the data presentation, the hypotheses for the study were analyzed and then discussed.

Energy Sources, Demand, Usage and Options in Nigeria Airports and Hangars

This section explores the current state of energy use in Nigerian airports through stakeholder surveys. Data presented in Table A1 and Figures [A1-A5] reveals that most airports rely on a combination of diesel generators (87.8%) and the national grid (83.2%) for electricity. However, nearly half (48.7%) of the airports utilize solar PV systems, indicating a growing interest in renewable energy. Daily energy demand typically peaks during the day (63.9%) due to airport operations, with some airports experiencing a flatter demand curve throughout the day (29.8%).

Limited funding (32.4%) and insufficient government incentives (29.0%) were identified as the biggest hurdles to achieving greater energy efficiency. Integrating renewable energy (15.5%) and a lack of awareness about energy-saving technologies (14.3%) were also cited as barriers.

Stakeholders expressed significant concerns regarding the adoption of hybrid renewable energy systems (HRES) in airports. The high initial investment cost (52.1%) was the primary concern, followed by anxieties about the reliability of renewable energy sources (30.3%) and the maintenance requirements of HRES installations (29.8%). Compatibility with existing grid infrastructure (17.6%) was another concern.

To address these concerns and facilitate HRES adoption, stakeholders emphasized the importance of: Conducting feasibility studies and cost analysis (14.7%); Provide training programmes on HRES operation and maintenance (10.9%), and; Securing government financial assistance (10.1%). A combination of these strategies was viewed as the most effective approach (62.2%).

Techno-Economic framework for HRES in airports and hangars

This section investigates key factors influencing the adoption of hybrid renewable energy systems (HRES) in Nigerian airports, as depicted in Table B1 and Figures [B1-B4). Stakeholders overwhelmingly favoured tax reductions (73.1%) as the most preferred policy incentive to encourage HRES adoption. A simplified permitting process (46.2%) and feed-in tariffs for excess electricity generation (26.5%) were also viewed favourably. Regarding financing options, a significant majority of respondents (75.2%) considered reliable financing through loans or grants to be extremely or very important for making HRES projects feasible.

Technical expertise within Nigeria for HRES design, installation, and maintenance was a key concern. While over half (52.1%) of respondents expressed confidence in available expertise, a significant portion (24.8%) were only reasonably confident. To overcome challenges and promote HRES adoption, stakeholders emphasized the importance of: Government incentives (51.3%); Development of financing mechanisms (29.4%), and; Clear policies and regulations (34.0%). A combination of these strategies was viewed as most effective by nearly half (46.2%) of respondents.

Cost savings potential from renewable energy in Nigerian Airports

Table C1 demonstrations analysis on hypothesis H_0 (1): “There is a potential for significant cost savings through the adoption of renewable energy in Nigeria airports”. A linear multiple regression model test was carried out on questions relating to potential for significant cost savings through the adoption of renewable energy in Nigeria airports. The linear multiple regression model that described this relationship is given as

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \epsilon$$

This model has k regressor variables. The true functional relationship between Y and $x_1, x_2, \ldots, x_k$ is unknown, but over certain ranges of the independent variables the linear regression model is an adequate approximation (Douglas and George, 2003). The parameters βj, j=0, 1, …,k, are called the regression coefficients. This model describes a hyper-plane in the k-dimensional space of the regressor variables $\{x_j\}$. The parameter βj represents the expected change in response Y per unit change in x_j when all the remaining regressors x_i ($i \neq j$) are held constant. ϵ is the random error term.

So, hypothesis H_0 (1) investigates the potential for cost savings through renewable energy adoption in Nigerian airports. While the regression analysis yielded a significant relationship between cost savings and factors like "reduction in long-term electricity costs" (β_4 = 0.194, $p < 0.001$) and "comfort of integrating solutions" (β_5 = 0.113, $p < 0.009$), the overall model explained only 15.1% (R^2 from the Model Summary^b) for the table of the variance in cost savings. Furthermore, the regression coefficients for key factors like "expenditure on electricity bills" (β_2 = 0.082, $p < 0.820$) and “potential cost impact” (β_3 = -0.254, $p < 0.266$) were statistically insignificant. Based on these findings, the null hypothesis ($H_0$1) stating "There is a potential for significant cost savings through the adoption of renewable energy in Nigerian airports" was rejected. The alternate hypothesis ($H_1$1) suggesting "There is insignificant cost savings through the adoption of renewable energy in Nigerian airports" was tentatively accepted. The result may be due to the limited existing HRES installations in the surveyed airports, leading to a lack of concrete data on cost savings from renewable energy sources.

Government policies and financing for HRES adoption

This hypothesis then examined the impact of government policies and financing on the adoption of hybrid renewable energy systems (HRES) in Nigerian airports and hangars (Table D1). While a regression analysis indicated a significant relationship between “access to reliable financing” and "willingness to invest" in HRES (β_1 = 0.061, $p < 0.014$), the overall model explained only 4% (R^2) of the variance. Similarly, “government financial support” (β_2 = 0.073, $p < 0.393$) and “information or support resources” (β_3 = 0.052, $p < 0.869$) showed no statistically significant impact on willingness to invest. Based on these findings, the null hypothesis ($H_0$2) stating "Supportive government policies (incentives, regulations) and access to financing will significantly encourage the adoption of HRES in Nigeria airports" was rejected. The alternate hypothesis ($H_1$2) suggesting "Supportive government policies (incentives, regulations) and access to financing will insignificantly encourage the adoption of HRES in Nigeria airports" was tentatively accepted. This suggests that while access to financing may play a role, government policies and access to information on its own may not be substantial drivers for HRES adoption in these airports.

CONCLUSIONS

This study investigated the current state of energy use and the potential for adopting Hybrid Renewable Energy Systems (HRES) in Nigerian airports. Stakeholders expressed interest in HRES, but challenges such as financing limitations and concerns about reliability and maintenance costs were identified. While some evidence suggests cost savings might be achievable, more data from existing HRES installations is needed for confirmation.

To facilitate HRES adoption, the study recommends a combination of approaches. First, policymakers should prioritize establishing reliable financing mechanisms like loans and grants specifically designed for HRES projects. Second, stakeholders need capacity building initiatives to address concerns about HRES reliability and maintenance. Finally, conducting feasibility studies at specific airports with strong interest in HRES can provide tailored roadmaps for successful implementation. By addressing these recommendations, Nigerian airports can unlock the potential of HRES to enhance energy security and environmental sustainability.

REFERENCES

1. OGBONNAYA, C., ABEYKOON, C., DAMO, U.M. & TURAN, A. (2019). The current and emerging renewable energy technologies for power generation in Nigeria: A review. *Thermal Science and Engineering Progress*, **13**(2019): 100390. ISSN 2451-9049.
2. SHAABAN, M. & PETINRIN, J.O. (2014). Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renewable and Sustainable Energy Reviews*, **29**(January 2014): 72-84.
3. IGBINOVIA, F.O. (2014). An Overview of Renewable Energy Potentials in Nigeria: Prospects, Challenges and the Way Forward. *Researchgate*.
4. NWOZOR, A., OSHEWOLO, S., OWOEYE, G. & OKIDU, O. (2021). Nigeria’s quest for alternative clean energy development: A cobweb of opportunities, pitfalls and

multiple dilemmas. *Energy Policy,* **149**(February 2021): 112070
5. INTERNATIONAL ENERGY AGENCY, IEA, (2023). World Energy Outlook 2023. IEA Publications.
6. ORUKPE, P.E., ONIANWA, C.T., ABUH, A. & ADERANTI, A.K. (2020). Reliability Assessment of Power Distribution System in the Nigerian Aviation Industry. *Journal of Engineering, Science and Computing,* **2**(2): 37-54.
7. BAJPAI, P. & DASH, V. (2012). Hybrid renewable energy systems for power generation in stand-alone applications: A review. *Renewable and Sustainable Energy Reviews*, **16**(5): 2926-2939.
8. PRABODH, B. & VAISHALEE, D. (2012). Hybrid renewable energy systems for power generation in stand-alone applications: A review. *Journal of Renewable and Sustainable Energy Reviews*, **16**(5): 2926-2939.
9. DAVIS, F.D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, **13**(3): 319-340.
10. DEARING, J.W. & COX, J.G. (2018). Diffusion of Innovations Theory, Principles, And Practice. *Health Affairs,* **37**(2): 183–190.
11. SCOTT, W.R. (2004). Institutional Theory: Contributing to a Theoretical Research Program. In *Great Minds in Management: The Process of Theory Development*, Ken G. Smith and Michael A. eds. Oxford UK: Oxford University Press.
12. AMY, J.H., MICHAEL, C.W. & BRIAN, J.C. (2009). Resource Dependence Theory: A Review. *Journal of Management,* **35**(6): 1404–1427.
13. CHUKWU, P.U., ISA, A.H., OJOSU, J.O. & OLAYANDE, J.S. (2015). Energy Consumption in Transport Sector in Nigeria: Current situation and ways forward. *Journal of Energy Technologies and Policy,* **5**(1): 75-83 ISSN 2224-3232.
14. ORIKPETE, O.F., GUNGURA, N.M., EHIMARE, E. & EWIM, D.R.E. (2023). A critical review of energy consumption and optimization strategies in the Nigerian aviation sector: challenges and prospects. *Bulletin of the National Research Centre,* (2023): 47:170.
15. INTERNATIONAL ENERGY AGENCY, IEA (2019). *World Energy Outlook 2019.* International Energy Agency. ISBN 9789264973008
16. BELGANA, S., DABIB, A., BILIL, H. & MAAROUFI, M. (2013). Hybrid Renewable Energy System Design using Multobjective Optimization. *ResearchGate*, Pp. 1-7
17. BERNAL-AGUSTÍN, J.L. & DUFO-LÓPEZ, R. (2009). Simulation and optimization of stand-alone hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews,* **13**(8): 2111-2118.
18. DESHMUKH, M.K. & DESHMUKH, S.S. (2008). Modeling of hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, **12**(1): 235-249.
19. SINHA, S. & CHANDEL, S. (2014). Review of software tools for hybrid renewable energy systems. *Renewable and Sustainable Energy Review,* **32**(2014): 192-205
20. OLUSOLA, B., MUSTAFA, D., AKINOLA, B. & OLUWASEUN, A. (2017). A review of renewable energy potential in Nigeria; solar power development over the years. *Engineering and Applied Science Research* October – December 2017; **44**(4): 242-248.
21. AKINYELE, D., OLATOMIWA, L., IGHRAVWE, D.E., BABATUNDE, M.O., MONYEI, C. & AIKHUELE, D. (2020). Optimal planning and electricity sharing strategy of hybrid energy system for remote communities in Nigeria. *Journal of Scientific African*, **10**(2020) e00589: 1-11.
22. OWEBOR, K., DIEMUODEKE, E.O., BRIGGS, T.A. & IMRAN, M. (2021). Power Situation and renewable energy potentials in Nigeria– A case for integrated multi-generation technology. *Renewable Energy*, **177**(November 2021): 773-796.
23. OZOEGWU, C.G., MGBEMENE, C.A. & OZOR, P.A. (2017). The status of solar energy integration and policy in Nigeria. *Renewable and Sustainable Energy Reviews*, **70**(2017): 457–471.
24. MONYEI, C.G., ADEWUMIA, A.O., OBOLO, M.O. & SAJOU, B. (2017). Nigeria's energy poverty: Insights and implications for smart policies and framework towards a smart Nigeria electricity network. *Renewable and Sustainable Energy Reviews*, **81**(2018): 1582–1601.
25. MOHAMMED, Y.S., MUSTAFA, M.W., BASHIR, N. & IBRAHEM, I.S. (2017). Existing and recommended renewable and sustainable energy development in

Nigeria based on autonomous energy and microgrid technologies. *Renewable and Sustainable Energy Reviews*, **75**(2017): 820–838.

26. SAMBO, A. (2009). Strategic Developments in Renewable Energy in Nigeria. *Research Gate*, pp. 15–19.
27. SAMBO, A.S. & BALA, E.J. (2012). Penetration of solar photovoltaic into Nigeria's energy supply mix. Paper presented at the ASES/WREF 2012, Denver Colorado. https://ases.conference-services.net/resources/252/2859/pdf/SOLAR2012_0906_full%20paper.pdf.

Table A1: Energy sources, demand, usage and options in Nigeria airports

Statistics														
		What are the energy source(s) that power the infrastructure and facilities within your airport?	What are the energy source(s) that power the infrastructure and facilities within your airport?	What are the energy source(s) that power the infrastructure and facilities within your airport?	What are the energy source(s) that power the infrastructure and facilities within your airport?	Others specify	Regarding daily energy demand at your airport/hangar, which best describes the typical pattern?	In your opinion, which of the following is the biggest challenge to achieving greater energy efficiency in Nigeria airports?	Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?	Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?	Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?	Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?	Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?	Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?
N	Valid	198	21	209	116	238	237	234	124	71	42	72	42	236
	Missing	40	217	29	122	0	1	4	114	167	196	166	196	2

Frequency Table

1. What are the energy source(s) that power the infrastructure and facilities within your airport?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	National Grid Supply	198	83.2	100.0	100.0
Missing	System	40	16.8		
Total		238	100.0		

1. What are the energy source(s) that power the infrastructure and facilities within your airport?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Private Grid Supply	21	8.8	100.0	100.0
Missing	System	217	91.2		
Total		238	100.0		

1. What are the energy source(s) that power the infrastructure and facilities within your airport?					
		Frequency	Percent	Valid Percent	Cumulative Percent

Valid	Diesel Generator	209	87.8	100.0	100.0
Missing	System	29	12.2		
Total		238	100.0		

1. What are the energy source(s) that power the infrastructure and facilities within your airport?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Solar PV Power System	116	48.7	100.0	100.0
Missing	System	122	51.3		
Total		238	100.0		

2. Regarding daily energy demand at your airport/hangar, which best describes the typical pattern?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highest demand during the day, lowest at night	152	63.9	64.1	64.1
	Highest demand in the evening, lowest in the morning	7	2.9	3.0	67.1
	Relatively constant demand throughout the day	71	29.8	30.0	97.0
	Unsure/Don't Know	7	2.9	3.0	100.0
	Total	237	99.6	100.0	
Missing	System	1	.4		
Total		238	100.0		

3. In your opinion, which of the following is the biggest challenge to achieving greater energy efficiency in Nigeria airports?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Lack of awareness about energy-saving technologies	34	14.3	14.5	14.5
	Limited access to funding for energy efficiency upgrades	77	32.4	32.9	47.4
	Difficulty in integrating renewable energy sources	37	15.5	15.8	63.2
	Insufficient government incentives for energy efficiency	69	29.0	29.5	92.7
	Unsure/don't know	17	7.1	7.3	100.0
	Total	234	98.3	100.0	
Missing	System	4	1.7		
Total		238	100.0		

4. Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Initial investment cost	124	52.1	100.0	100.0
Missing	System	114	47.9		
Total		238	100.0		

4. Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Maintenance requirements	71	29.8	100.0	100.0
Missing	System	167	70.2		
Total		238	100.0		

4. Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Compatibility with existing grid infrastructure	42	17.6	100.0	100.0
Missing	System	196	82.4		
Total		238	100.0		

4. Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Reliability of renewable energy sources	72	30.3	100.0	100.0
Missing	System	166	69.7		
Total		238	100.0		

4. Do you have any of the following concerns regarding the implementation of HRES at your airport/hangar?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	None of the above	42	17.6	100.0	100.0
Missing	System	196	82.4		
Total		238	100.0		

5. Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Feasibility studies and cost analysis of HRES for airports	35	14.7	14.8	14.8
	Training programs on operation and maintenance of HRES	26	10.9	11.0	25.8
	Financial assistance for HRES implementation projects	24	10.1	10.2	36.0
	All of the above	148	62.2	62.7	98.7
	None of the above	3	1.3	1.3	100.0
	Total	236	99.2	100.0	
Missing	System	2	.8		
Total		238	100.0		

Source: Field survey (2024)

Table B1: Frequency Table

Which of the following policy incentives would most encourage your airport/hangar to consider adopting HRES solutions?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Feed-in tariffs for excess electricity generated	63	26.5	100.0	100.0
Missing	System	175	73.5		
Total		238	100.0		

Which of the following policy incentives would most encourage your airport/hangar to consider adopting HRES solutions?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Reduced tax liabilities for airports	174	73.1	100.0	100.0
Missing	System	64	26.9		
Total		238	100.0		

Which of the following policy incentives would most encourage your airport/hangar to consider adopting HRES solutions?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Simplified permitting process for HRES installation	110	46.2	100.0	100.0
Missing	System	128	53.8		
Total		238	100.0		

How important is access to reliable financing options (loans, grants) for making HRES a feasible option for your airport/hangar?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all important	8	3.4	3.4	3.4
	Slightly important	23	9.7	9.9	13.3
	Moderately important	23	9.7	9.9	23.2
	Very important	108	45.4	46.4	69.5
	Extremely important	71	29.8	30.5	100.0
	Total	233	97.9	100.0	
Missing	System	5	2.1		
Total		238	100.0		

How confident are you in the technical expertise available in Nigeria for the design, installation, and maintenance of HRES for airports?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all confident	8	3.4	3.4	3.4
	Somewhat confident	21	8.8	8.9	12.3
	Neutral	23	9.7	9.8	22.1
	Moderately confident	59	24.8	25.1	47.2
	Very confident	124	52.1	52.8	100.0
	Total	235	98.7	100.0	
Missing	System	3	1.3		
Total		238	100.0		

In your opinion, which of the following factors would be most helpful in overcoming challenges and promoting the adoption of HRES in Nigeria airports?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Government incentives that encourage investment	122	51.3	100.0	100.0
Missing	System	116	48.7		
Total		238	100.0		

In your opinion, which of the following factors would be most helpful in overcoming challenges and promoting the adoption of HRES in Nigeria airports?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Development of financing mechanisms to support	70	29.4	100.0	100.0
Missing	System	168	70.6		
Total		238	100.0		

In your opinion, which of the following factors would be most helpful in overcoming challenges and promoting the adoption of HRES in Nigeria airports?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Establishment of clear policies and regulations	81	34.0	100.0	100.0
Missing	System	157	66.0		
Total		238	100.0		

In your opinion, which of the following factors would be most helpful in overcoming challenges and promoting the adoption of HRES in Nigeria airports?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	All of the above	110	46.2	100.0	100.0
Missing	System	128	53.8		
Total		238	100.0		

In your opinion, which of the following factors would be most helpful in overcoming challenges and promoting the adoption of HRES in Nigeria airports?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Unsure	8	3.4	100.0	100.0
Missing	System	230	96.6		
Total		238	100.0		

Source: Field survey (2024)

Table C1: Linear Regression Statistical Test for Hypothesis H_01

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	How comfortable would your airport/hangar be with integrating energy storage solutions (batteries and biomass stock-feeds) as part of a hybrid renewable energy system?, Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?, How important is a potential reduction in your airport/hangar's long-term electricity costs when considering renewable energy solutions?, What is your current monthly expenditure on electricity bills for your airport/hangar operations (in Naira)?, Based on your understanding, which of the following statements best reflects the potential cost impact of implementing HRES at your airport/hangar compared to relying solely on the national grid?[b]	.	Enter

a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?
b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.389[a]	.151	.127	.84901

a. Predictors: (Constant), How comfortable would your airport/hangar be with integrating energy storage solutions (batteries and biomass stock-feeds) as part of a hybrid renewable energy system?, Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?, How important is a potential reduction in your airport/hangar's long-term electricity costs when considering renewable energy solutions?, What is your current monthly expenditure on electricity bills for your airport/hangar operations (in Naira)?, Based on your understanding, which of the following statements best reflects the potential cost impact of implementing HRES at your airport/hangar compared to relying solely on the national grid?
b. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	22.379	5	4.476	6.209	.000[b]
	Residual	125.421	174	.721		
	Total	147.800	179			

a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?
b. Predictors: (Constant), How comfortable would your airport/hangar be with integrating energy storage solutions (batteries and biomass stock-feeds) as part of a hybrid renewable energy system?, Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?, How important is a potential reduction in your airport/hangar's long-term electricity costs when considering renewable energy solutions?, What is your current monthly expenditure on electricity bills for your airport/hangar operations (in Naira)?, Based on your understanding, which of the following statements best reflects the potential cost impact of implementing HRES at your airport/hangar compared to relying solely on the national grid?

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		

	(Constant)	3.199	.513		6.241	.000
	Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?	-.012	.054	-.016	-.228	.820
	What is your current monthly expenditure on electricity bills for your airport/hangar operations (in Naira)?	.065	.058	.082	1.115	.266
1	Based on your understanding, which of the following statements best reflects the potential cost impact of implementing HRES at your airport/hangar compared to relying solely on the national grid?	-.233	.069	-.254	-3.390	.001
	How important is a potential reduction in your airport/hangar's long-term electricity costs when considering renewable energy solutions?	.194	.073	.194	2.661	.009
	How comfortable would your airport/hangar be with integrating energy storage solutions (batteries and biomass stock-feeds) as part of a hybrid renewable energy system?	.117	.077	.113	1.517	.131

a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.0966	4.7654	4.3000	.35359	180
Residual	-2.54690	1.41103	.00000	.83706	180
Std. Predicted Value	-3.403	1.316	.000	1.000	180
Std. Residual	-3.000	1.662	.000	.986	180

a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?

Summary of Statistical Test for Hypothesis $H_0 1$

Hypothesis	**Regression Weights**	**Beta Coefficient**	**R^2**	**F**	**t-value**	**P-value**	**Hypothesis Supported**
$H_0 1$	Cost savings - information or support resources	-0.016	0.151	6.209	-0.228	0.000	No
	Cost savings - expenditure on electricity bills	0.082	0.151	6.209	1.115	0.820	No
	Cost savings - potential cost impact	-0.254	0.151	6.209	-3.390	0.266	No
	Cost savings - reductn in long-term elect costs	0.194	0.151	6.209	2.661	0.001	Yes
	Cost savings - comfort of integrating solutions	0.113	0.151	6.209	1.517	0.009	Yes

Table D1: Linear Regression Statistical Test for Hypothesis $H_0 2$

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?, How important is government financial support (subsidies, tax breaks) for making HRES a viable option for your airport/hangar?, How important is access to reliable financing options (loans, grants) for making HRES a feasible option for your airport/hangar?[b]		.Enter

a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?
b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.200[a]	.040	.027	.90028

a. Predictors: (Constant), Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?, How important is government financial support (subsidies, tax breaks) for making HRES a viable option for your airport/hangar?, How important is access to reliable financing options (loans, grants) for making HRES a feasible option for your airport/hangar?
b. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.476	3	2.492	3.075	.029[b]
	Residual	179.120	221	.810		
	Total	186.596	224			

a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?
b. Predictors: (Constant), Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?, How important is government financial support (subsidies, tax breaks) for making HRES a viable option for your airport/hangar?, How important is access to reliable financing options (loans, grants) for making HRES a feasible option for your airport/hangar?

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.436	.372		9.236	.000
	How important is government financial support (subsidies, tax breaks) for making HRES a viable option for your airport/hangar?	.063	.073	.060	.855	.393
	How important is access to reliable financing options (loans, grants) for making HRES a feasible option for your airport/hangar?	.150	.061	.173	2.464	.014
	Which of the following information or support resources would be most helpful for your airport/hangar to consider adopting HRES solutions?	.009	.052	.011	.165	.869

a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?

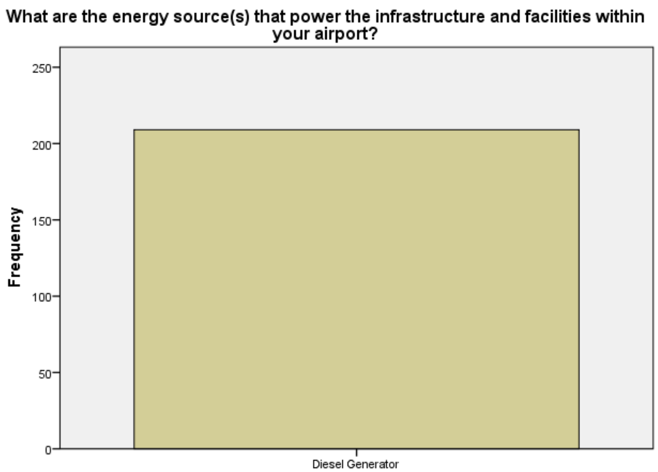
Residuals Statistics[a]

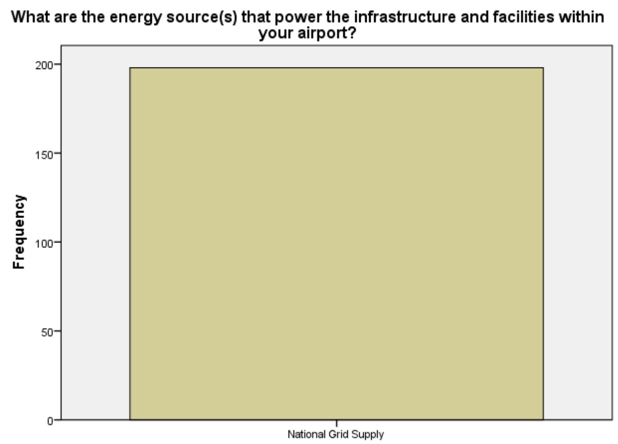
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.6911	4.5321	4.3156	.18269	225
Residual	-2.53208	1.12937	.00000	.89423	225
Std. Predicted Value	-3.418	1.185	.000	1.000	225
Std. Residual	-2.813	1.254	.000	.993	225

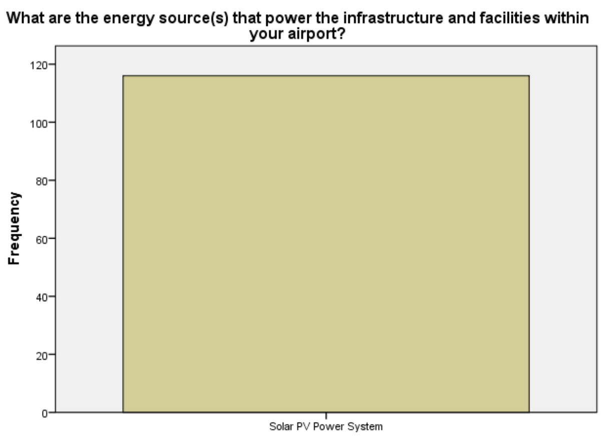
a. Dependent Variable: How willing would your airport/hangar be to invest in renewable energy solutions (like HRES) if there were significant long-term cost savings?

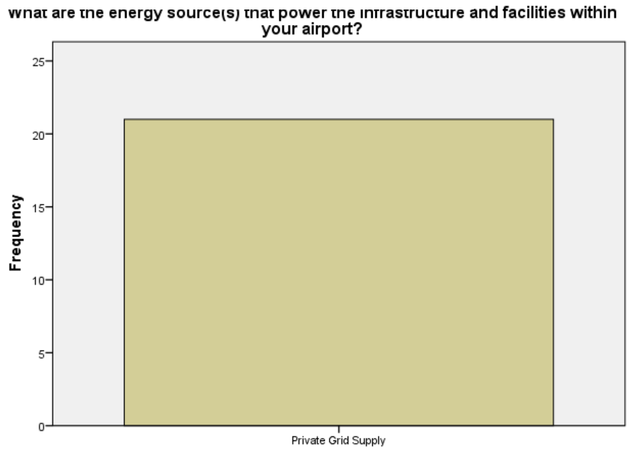
Summary of Statistical Test for Hypothesis H_02

Hypothesis	Regression Weights	Beta Coefficient	R^2	F	t-value	P-value	Hypothesis Supported
H_02	Willingness to Invest – Govt finan support	.073	0.040	3.075	.855	.393	No
	Willingness to Invest –Access to Rel finan	.061	0.040	3.075	2.464	.014	Yes
	Willingness to Invest –Info/support resour	.052	0.040	3.075	.165	.869	No









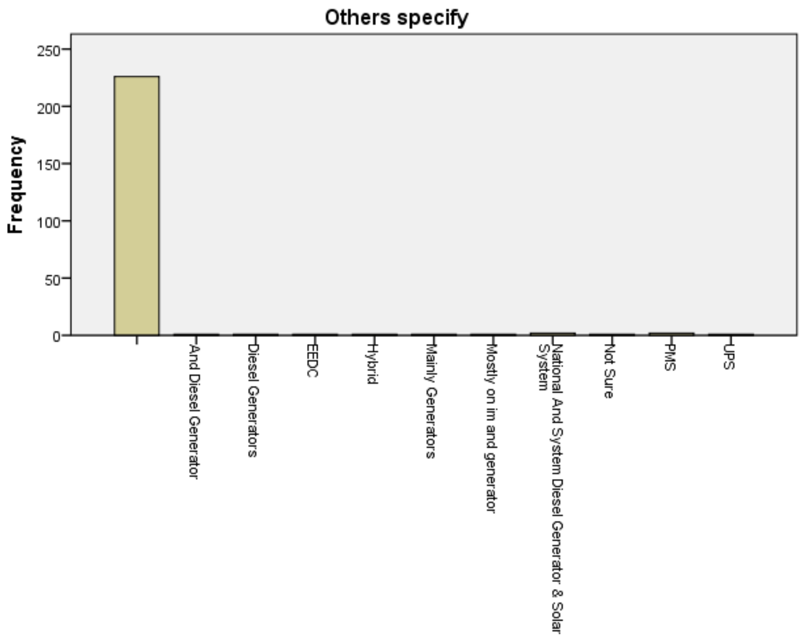


Figure A1: Energy sources for powering infrastructure and facilities within airports

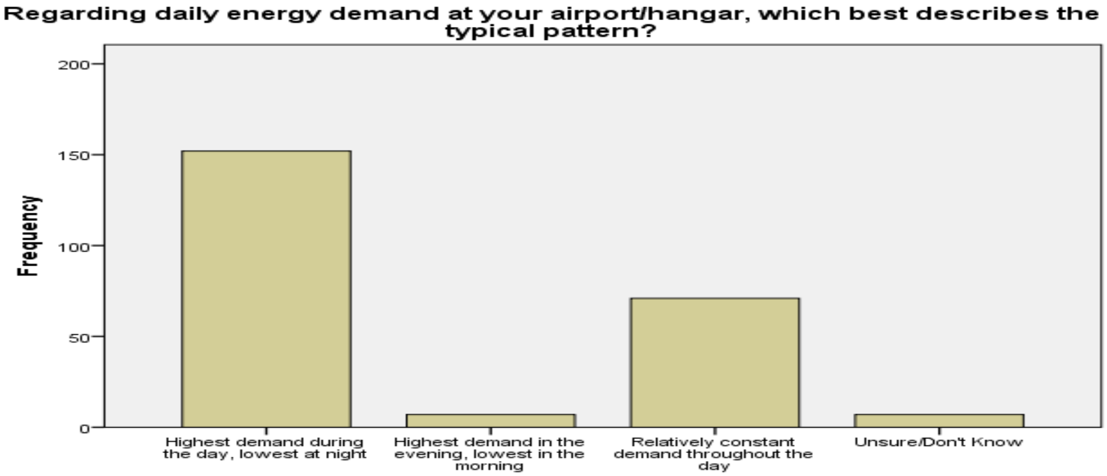


Figure A2: Peak periods for energy demand in airports

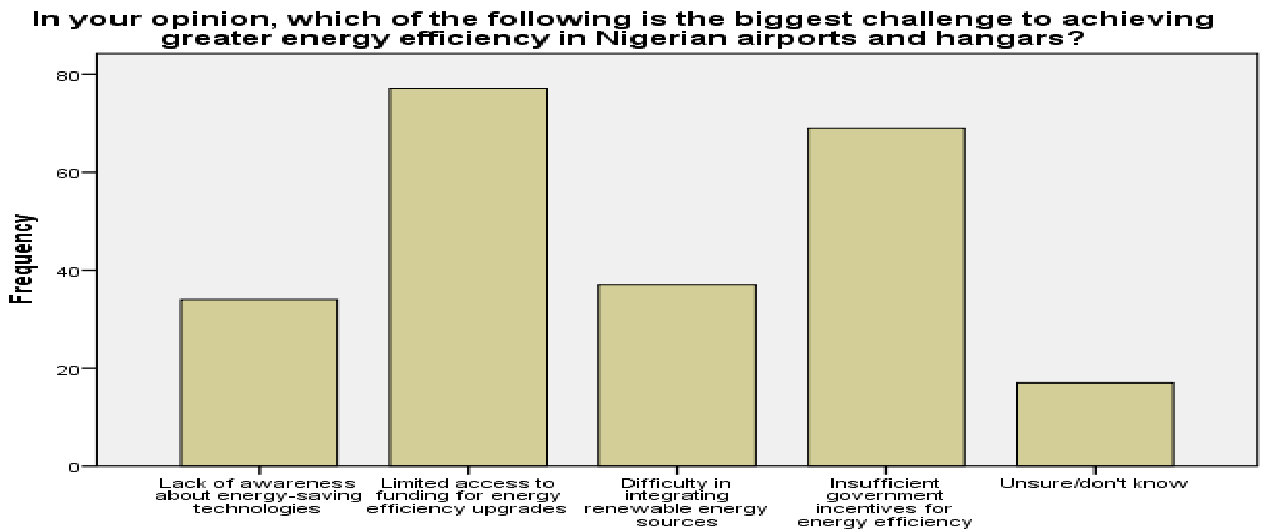


Figure A3: Barriers to energy efficiency in Nigeria airports

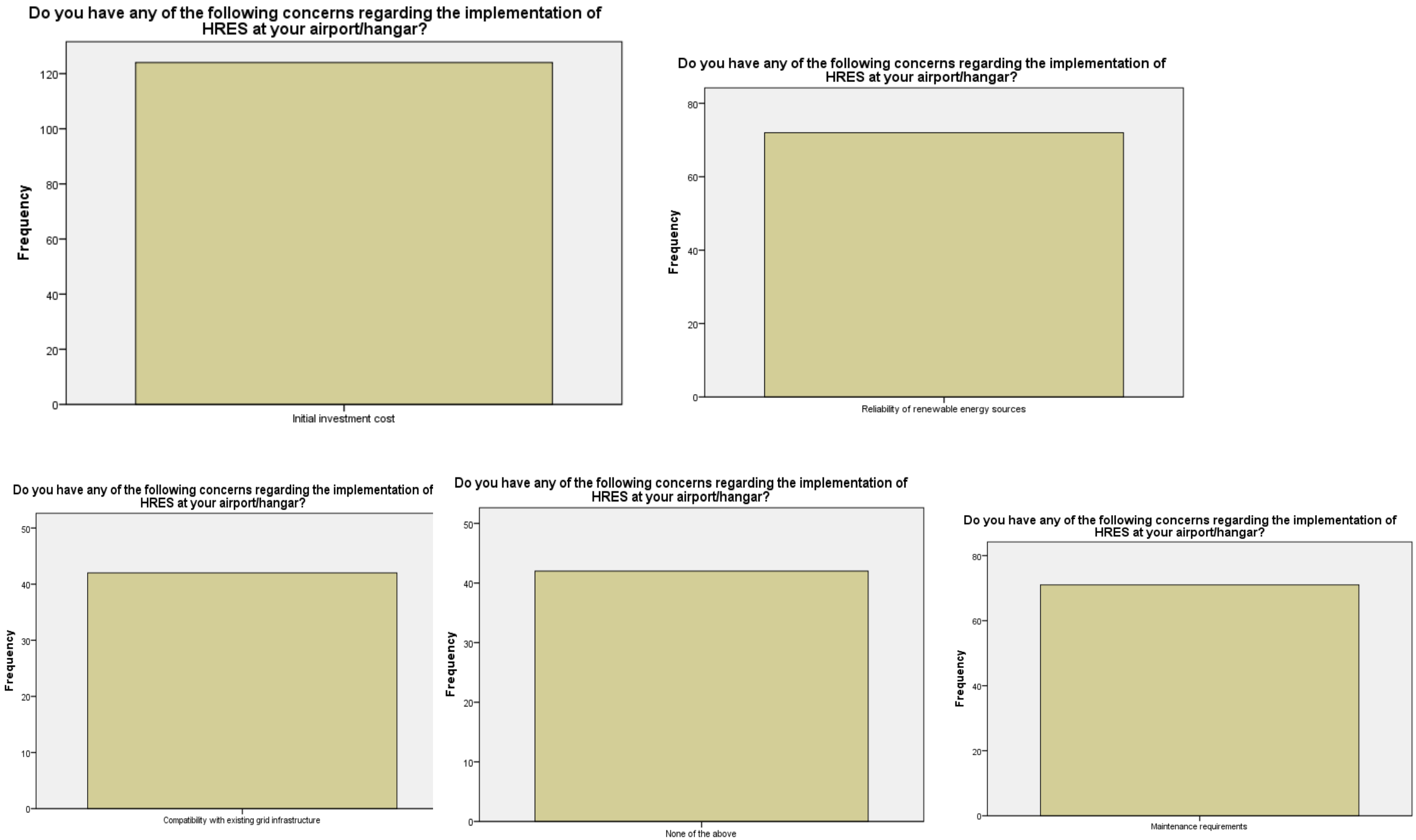


Figure A4: Factors influencing HRES implementation in airports

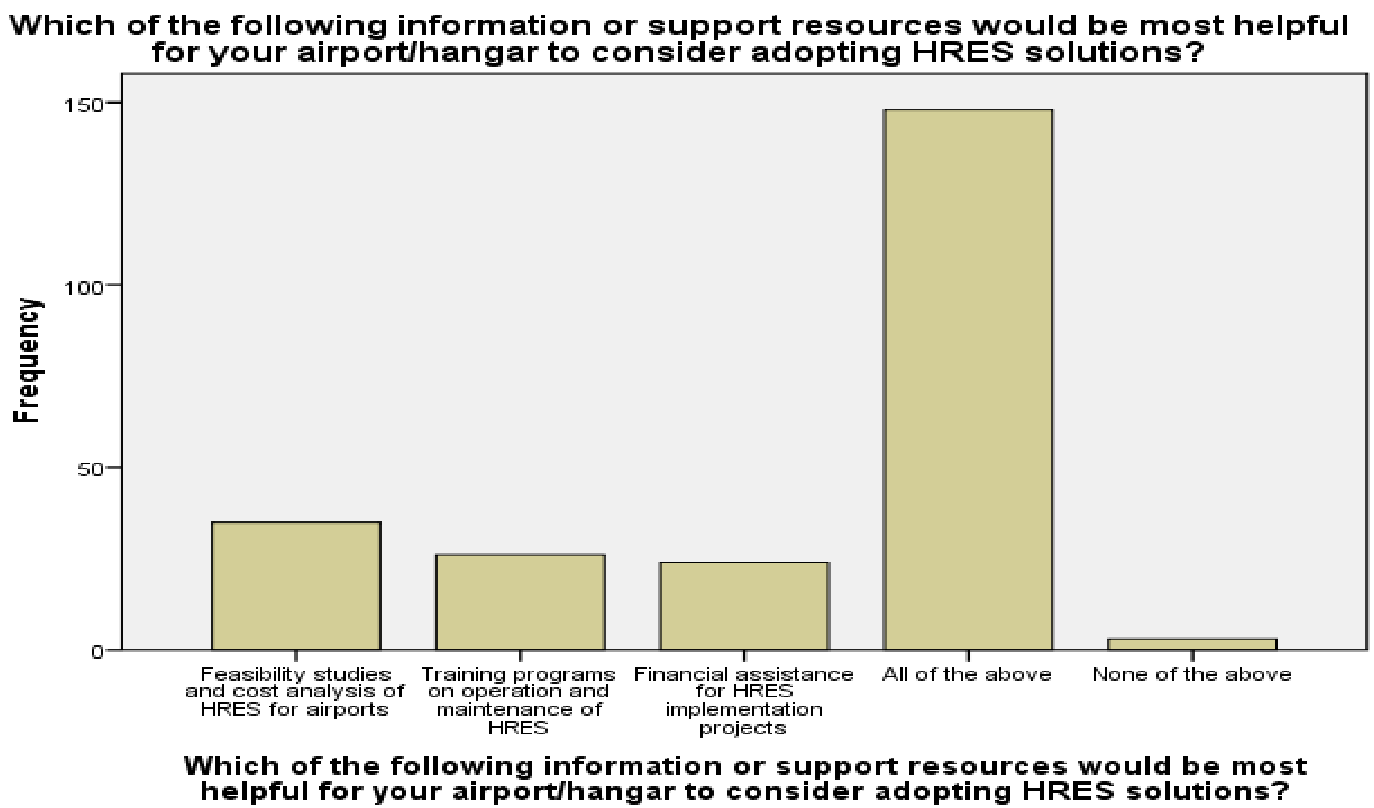
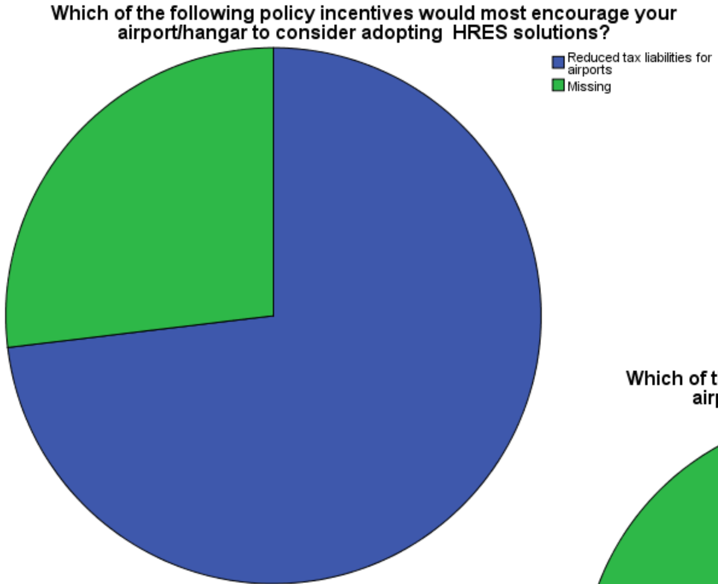
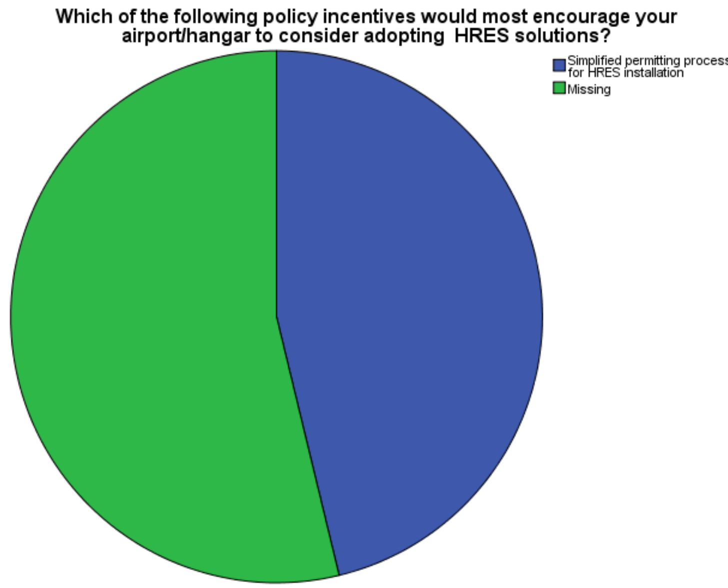


Figure A5: Support resources for adopting HRES solutions in airports





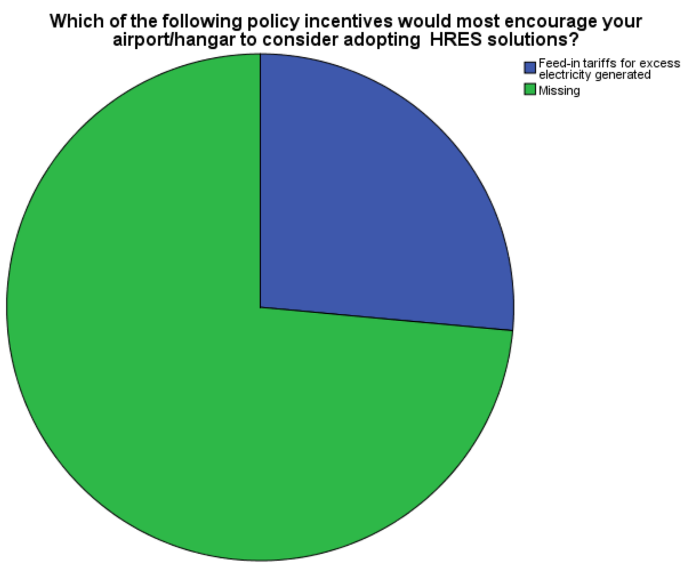


Figure B1: Preferred Policy Incentives for HRES Solutions

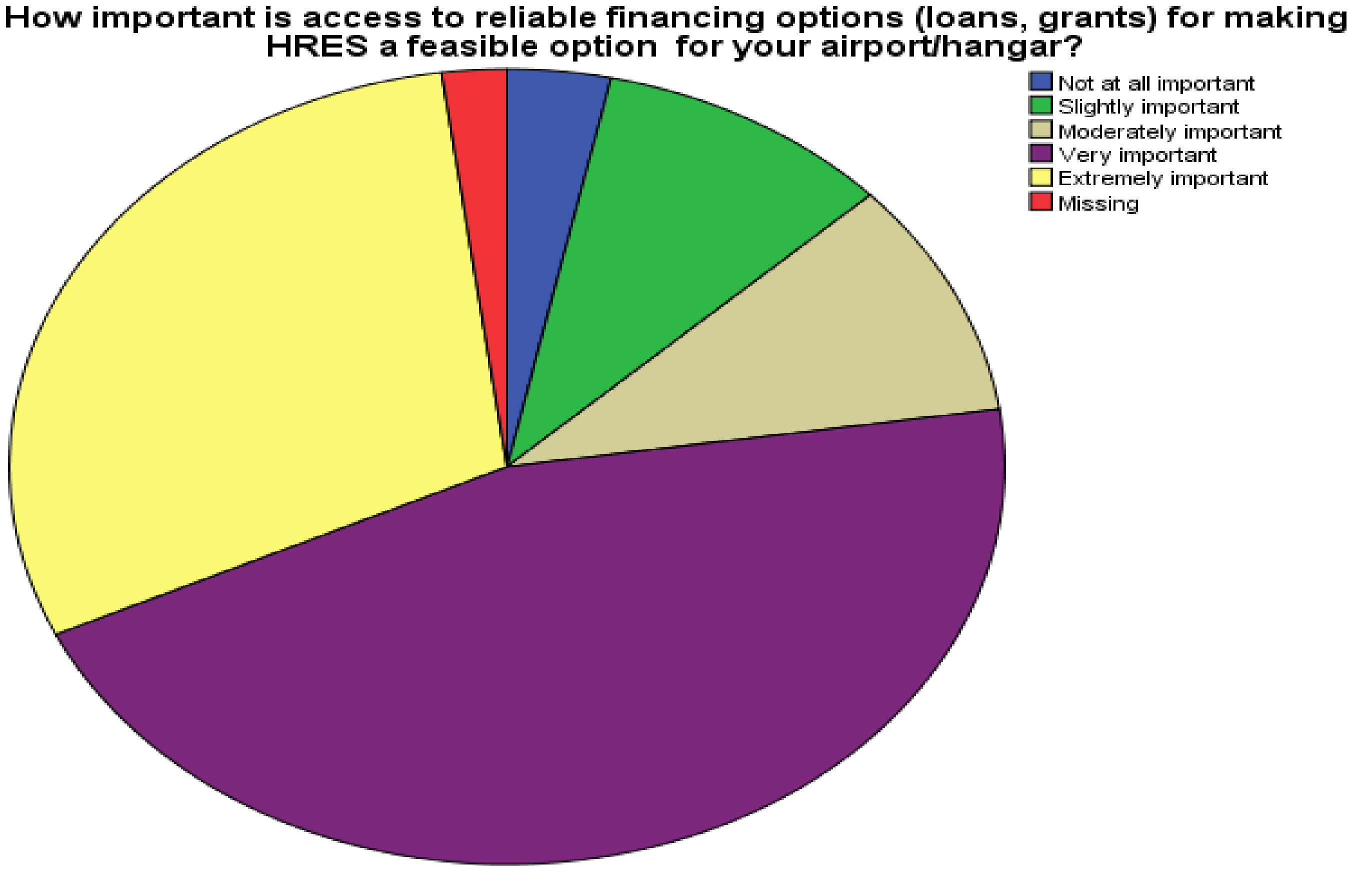


Figure B2: Importance of Financing Options for HRES Solutions

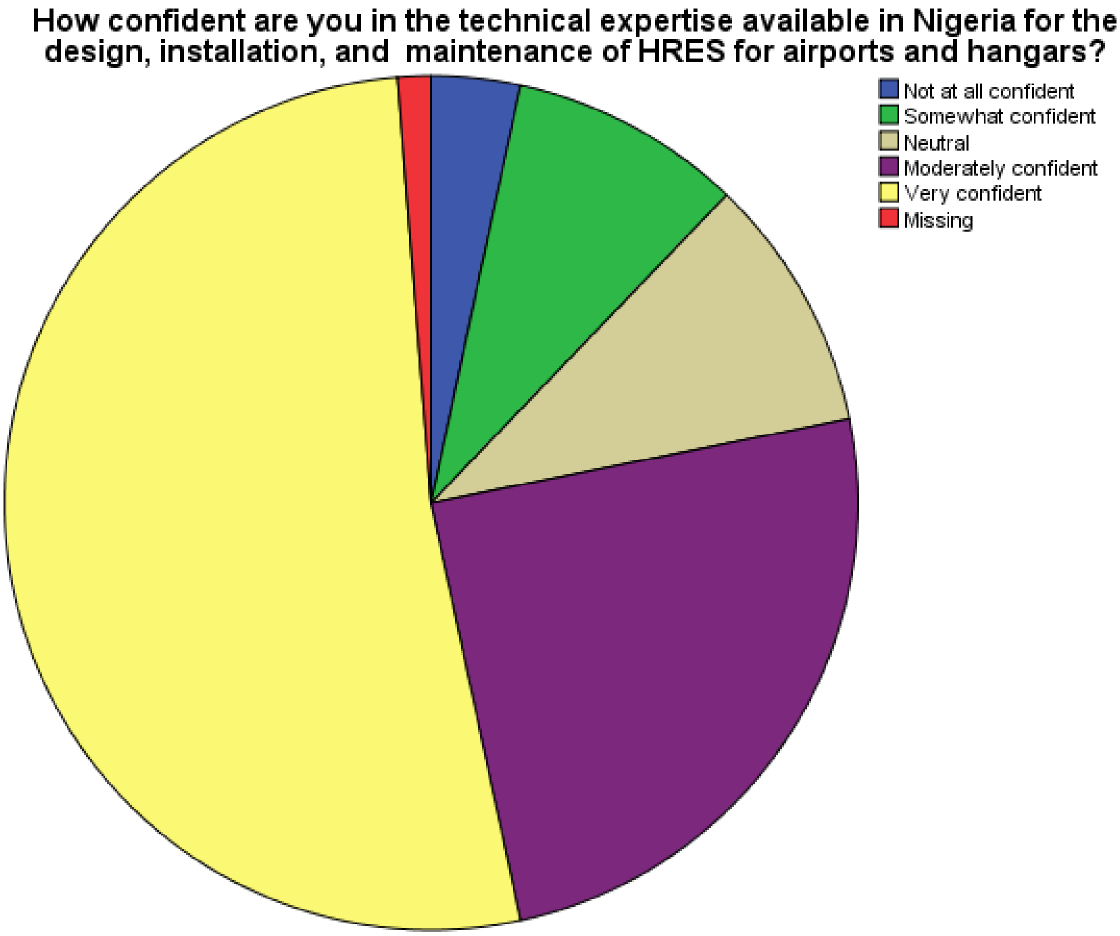


Figure B3: Confidence in HRES Technical Expertise in Nigeria

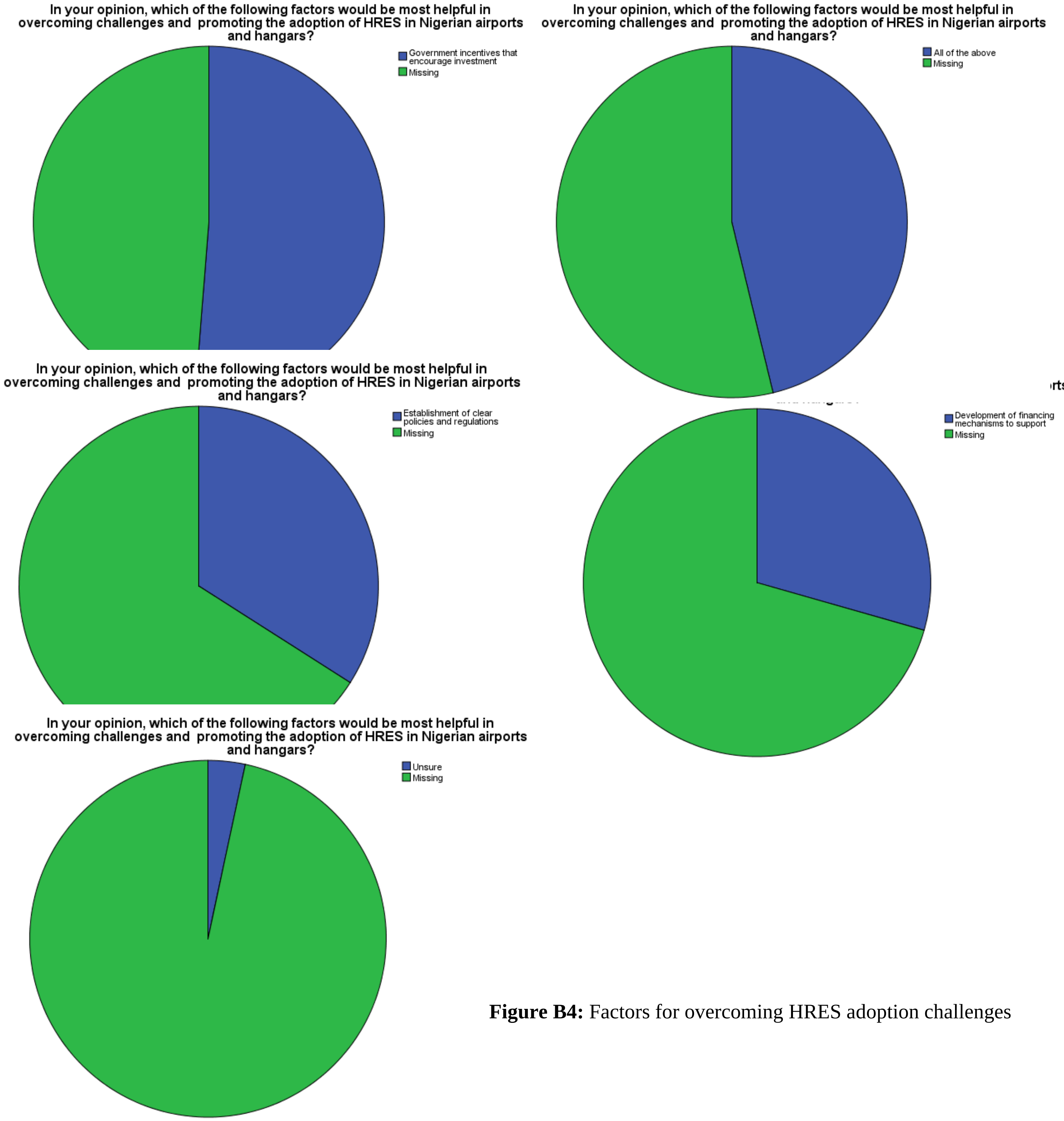


Figure B4: Factors for overcoming HRES adoption challenges