

POLICY AWARENESS AND WASTE MANAGEMENT CHALLENGES OF END-OF-LIFE SOLAR PV SYSTEMS IN THE NIGER DELTA, NIGERIA

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ABSTRACT

Purpose: Access to reliable electricity remains a critical challenge in Nigeria, driving increased deployment of solar power systems (SPSs) across the Niger Delta, with emerging concerns over the management of end-of-life solar photovoltaic (PV) waste streams. This study assesses the effectiveness of regulatory frameworks governing solar power systems (SPSs) value chains in Nigeria's Niger Delta, focusing on end-of-life solar photovoltaic (PV) waste management and stakeholder compliance amid rising electricity access challenges.

Design/methodology/approach: Primary data from 90 purposively selected stakeholders (recyclers, technicians, traders, importers) across Delta, Rivers, and Bayelsa States were collected via structured questionnaires. The data analysis employed descriptive statistics - frequency distributions, and multiple linear regression testing policy awareness, regulatory enforcement, financial incentives, and technical capacity against waste management effectiveness.

Findings: 63% of stakeholders lacked awareness of the National Environmental (Energy Sector) Regulations; 58% and 67% respondents were unaware of the NREEEP and NEEAP respectively. 58% of the stakeholders rated deployed strategies as inadequate; 73% respondents reported no collection targets; Over 60% noted absence of recycling incentives. Regression confirmed significant relationships ($p < 0.05$) for policy awareness ($\beta = 0.438$) being the strongest predictor of effectiveness in managing end-of-life SPSs.

Research limitations/implications: The purposive sampling deployed limits generalizability, and focused only on operational/expected stakeholders. There are calls for adopting the principles of extended producer responsibility (EPR) integration and comprehensive stakeholder training to bridge awareness and implementation gaps.

Practical implications: For resilience, regulators should urgently strengthen policy dissemination, establish periodic collection targets, provide formal recycling incentives, and enforce NESREA regulations and other relative policy tools to mitigate SPSs waste risks as Nigeria transit into renewable energy.

Originality/value: We first recorded the empirical analysis linking stakeholders' policy awareness to solar SPSs waste management effectiveness in the Niger Delta, rejecting a null hypothesis via regression ($R^2 = 0.507$).

Keywords: Solar power systems (SPSs), Green entrepreneurship, Niger Delta, Policy awareness, green wastes, NESREA regulations.

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1.0 INTRODUCTION

Solar energy, a sustainable green technology alternative reliant on the endless power of sunshine, has the potential to revolutionize energy use by transitioning to a cleaner energy model. In the Niger Delta, entrepreneurship in green technologies, especially solar power systems, presents vast opportunities to address energy shortages and environmental concerns. Leveraging abundant sunlight, solar energy can drive economic growth and create jobs while mitigating the impacts of fossil fuels. However, challenges like high initial costs, technical expertise, and inadequate infrastructure need to be tackled through innovative financing models, capacity building, and supportive policies. Solar energy, harnessed primarily through photovoltaic (PV) materials or solar cells, converts sunlight directly into electricity and is a renewable, environmentally friendly, cost-effective, and efficient energy source that particularly excels in low to medium power applications.

Over the past decades, numerous initiatives have spotlighted solar energy systems as a beacon of hope for broader energy accessibility across Africa and beyond. With a staggering figure of over 85 million Nigerians living without reliable energy access, solar energy offers a solution to the rising problems tied to fossil fuel depletion, climate change, pollution, high costs, and energy scarcity. The Federal Government of Nigeria remains committed to the Paris Accord obligations by taking innovative measures to bridge this energy gap. A highlight of these efforts is the issuance of the country's first green energy Bonds in 2017, generating a considerable ₦10.69 billion (US\$14 million). While encouraged by this success, the Federal Ministry of Environment proposed another ₦150 billion (about US\$200 million) green energy bond in 2018. These decisive actions underline the government's commitment to tackling energy accessibility, fostering green energy pursuit, and sustainable development in Nigeria.

Today, solar power is increasingly finding its way into the daily lives of Nigerians, powering everyday appliances in homes and offices. Green energy sources have emerged not only as an alternative energy solution combating climate change but also as an effective strategy for reducing energy bills. The solar energy generation process entails capturing sunlight using silicon cells embedded in solar photovoltaic (PV) panels, which contribute to solar waste streams. Solar power systems are primarily made up of PV panels, a DC to AC converter, a power conditioning system (PCS), backup batteries, and a rack for mounting the panels. Some solar power systems come as stand-alone devices, often referred to as solar panels or stand-alone photovoltaic (PV) systems, while others function as a combination of components. Although the main constituent of solar PV panels, glass, doesn't hold much value for recycling, they contain traces of valuable materials like silicon, copper, and silver.

A rising concern is the growing volume of decommissioned solar PV panels from various sectors, with an annual growth rate of 42% since 2010. These green wastes stem from diverse settings, including domestic, commercial, and industrial, and call for efficient waste management strategies. Numerous reports on waste management have underscored persistent, unresolved challenges threatening the biodiversity of the Niger Delta ecosystem in Nigeria. Green wastes from decommissioned solar power equipment have been linked to disrupting Nigeria's ambitions for pursuing its sustainable green energy drive. The handling of these end-of-life solar power systems in Nigeria is essentially a matter of collection rather than a structured recycling process, thereby creating further environmental quandaries. This paper primarily intends to examine the government guidelines for dealing with the value chain of solar power systems (SPSs) in the Niger Delta region of Nigeria.

2.0 THEORETICAL FRAMEWORK

The rapid expansion of solar PV systems (SPSs) deployment in the Niger Delta region presents both economic prospects and environmental risks, as end-of-life SPSs can generate significant value through recovery, repair and reuse (International Renewable Energy Agency, IRENA, 2016). This study is anchored on the intersection of green entrepreneurship, circular economy, and e-waste management concept. Green entrepreneurship emphasizes the role of renewable energy technologies, such as SPSs, in creating economic opportunities while addressing environmental challenges through innovation and sustainable enterprise development. The pursuit of green entrepreneurship clearly drives SPSs adoption in Nigeria by fostering economic opportunities through job creation in installation, maintenance, and recycling, transforming energy challenges into sustainable ventures in many places, including the Niger Delta. This aligns with the Schumpeterian innovation theory, where entrepreneurs innovate to address environmental gaps like unreliable grids (Schaltegger and Wagner, 2011).

The circular economy framework supports this transition by promoting closed-loop systems that prioritize reuse, recycling, and resource recovery of PV components/materials (e.g., silicon, silver), thereby enhancing material efficiency, minimizing waste from projected 78 million tonnes globally by 2050 and extending module lifespans via second-life applications (Schaltegger and Wagner, 2011; Krishnan, A., *et al.*, 2022). Global projections estimate that PV waste could reach 60–78 million tonnes by 2050, reinforcing the urgency for circular approaches. Consequently, IRENA emphasizes closed-loop systems to recover value and reduce environmental impacts.

In Nigeria, e-waste management is anchored in extended producer responsibility (EPR) under the NESREA's National Environmental (Electrical/Electronic Sector) Regulations 2022, which provides a governance mechanism by assigning lifecycle responsibility to producers for collection, recycling, and disposal (NESREA, 2022). EPR-based systems have been shown to incentivize environmentally sound product design and waste management practices including handling, collection and recycling. However, this 2022 NESREA Regulations remains weakly implemented (Okorhi *et al.*, 2023), creating gaps this study seeks to address.

3.0 LITERATURE REVIEW

3.1 Green energy quest and government commitments to solar power systems option for Nigeria.

Reports indicate that the Federal Government of Nigeria (FGN) has ensured a progressive policy direction on diversifying Nigeria's energy mix to promote the acceptance and usage of renewable energy as a major energy source. One way the government has demonstrated this is by creating a level playing field, political will, and commitments in developing plans for off-grid sub-sectors powered by renewable energy setups. The Nigeria Renewable Energy and Energy Efficiency Policy (NREEEP), 2015, projects an estimated investment of US\$3.5 billion to achieve 30GW of electricity generation by 2030. In addition, Nigeria is considered one of the fastest-growing markets for solar power systems (SPSs), driven by persistent inadequacies in grid electricity supply affecting several businesses and over 85 million citizens. While this rapid expansion supports energy access, it simultaneously signals a growing and under-addressed stream of end-of-life solar photovoltaic (PV) wastes, which is projected to increase significantly with the rising deployment and eventual decommissioning of such SPSs components.

According to industry estimates, the solar PV market in Nigeria is valued at over US\$39 million and employs more than 10,000 people (John, 2023), with increasing adoption across residential, commercial, and agricultural sectors. Reports of SPSs installations in rural dwellings, marketplaces, and agricultural processing centres continue to rise annually. For example, solar-powered technologies such as the Innotech 18 Meter Tunnel Solar Dryer and solar-powered refrigeration systems in markets have enhanced agricultural productivity and reduced post-harvest losses by up to 40% and extended shelf life by 2 to 21 days (John *et al.*, 2023). However, this rapid proliferation of solar technologies, coupled with their finite lifespan, is generating a parallel increase in solar PV waste streams, including panels, batteries, and associated electronic components. The absence of structured end-of-life management systems for these materials therefore poses significant environmental and public health risks, including soil and water contamination from hazardous substances and the loss of recoverable valuable materials.

While the government has introduced policy frameworks to support renewable energy adoption and lifecycle management of SPSs, as outlined in Table 1, critical gaps persist in the governance and implementation of these regulations.

Table 1: Framework for solar PV power systems in Nigeria

Regulations/Laws/Legislations/Acts/ for Solar PV Power Systems Management in Nigeria		Proponents
i	National Environmental (Energy Sector) Regulations, 2014	National Environmental Standards and Regulations Enforcement Agency (NESREA)
ii	National Renewable Energy and Energy Efficiency Policy (NREEEP), 2015	Federal Ministry of Power
iii	National Energy Efficiency Action Plan, 2016 (NEEAP)	Federal Ministry of Power, Work and Housing
iv	National Renewable Energy Action Plan, 2016 (NREAP)	Federal Ministry of Power, Work and Housing
v	National Environmental (Sanitation and Wastes Control) Regulation S.I.28 of 2009	NESREA
vi	National Environmental (Electrical/Electronics Sector) Regulations, 2022	NESREA

Source: Management Strategies for Handling E-Waste from Solar Devices in selected Cities of the Niger Delta (John, 2023)

Despite the existence of these regulatory instruments, Nigeria continues to face significant challenges in policy implementation, enforcement, and stakeholder compliance within the renewable energy sector. Evidence suggests that the increasing influx of decommissioned and, in some cases, transboundary solar PV waste into Nigeria further exacerbates the scale and urgency of the problem (Okorhi *et al.*, 2023). Reports have highlighted that weak regulatory enforcement and economic disincentives – such as import duties of 5% and value-added tax (VAT) imposed on solar PV components – have constrained both market expansion and investment in sustainable waste management infrastructure (John, 2023). These conditions undermine national targets for achieving 30% electricity generation from renewable sources by 2030.

Besides, there are critical governance and practice gaps within the power sector. These include inadequate awareness and adoption of existing power policies among key stakeholders, absence of clearly defined collection targets and technical standards for PV wastes and handling, weak institutional coordination, and inadequate financial incentives to support formal recycling systems for decommissioned SPSs. Notably, the Extended Producer Responsibility (EPR) framework, especially its distinct benefits, stipulated under the National Environmental (Energy Sector) Regulations (2014), remains poorly understood and largely unimplemented. Apparently, the consequence is a predominantly informal and unregulated system of collection and disposal, which prioritizes recovery over environmentally sound recycling processes of decommissioned SPSs. This has not only heightened ecological risks in the fragile Niger Delta ecosystem but also undermines the sustainability of Nigeria's green energy transition.

4.0 MATERIALS AND METHODS

Due to the high visibility of installed capacities for Solar PV Systems (SPSs) and increasing sales, demand, and usage in major cities of the core Niger Delta, this study was conducted within selected Local Government Areas (LGAs) in Delta, Rivers, and Bayelsa States. A purposive sampling technique was adopted to select nine urbanized LGAs across these states, based on their high concentration of solar PV activities/installations and relevance to the study objectives. Table 2 presents the population distribution of the selected LGAs. Within this population, three key stakeholder categories – regulatory agencies, recyclers/technicians/traders, and end-users – were identified and investigated using structured questionnaires tailored to each group. The overall sample size of 400 respondents was determined using the Yamane (1967) formula for sample size estimation, while the proportional allocation and distribution of questionnaires across the study locations were guided by the method proposed by Ogbuene (2014) to ensure adequate representation.

However, of the 3 strata of 400 respondents, this study specifically reports results from the 90 recyclers/technicians/traders sampled, given their direct involvement in the operational value chain and management of solar PV systems and associated waste streams. A purposive and stratified sampling approach was used to select these respondents within this category, focusing on actors/experts whose activities span installation, maintenance, repair, recycling, collection and distribution of SPSs components. Table 3 provides the administration schedule of the questionnaires. For spatial representation, at least one urbanized LGA was selected from each state, and a range of ten questionnaires were administered per LGA to relevant stakeholders. In total, 90 questionnaires were administered to this category, out of which 82 were retrieved and 73 were validated for analysis, representing an effective response rate of 81.11%.

The respondents comprised technicians, traders, recyclers, importers, and other intermediaries engaged in manufacturing, fabrication, scavenging, refurbishment, and recovery of solar PV systems components such as panels, lithium/acid-lead batteries, inverters, switches, cables and others. Data obtained were analysed using descriptive and inferential statistical techniques via regression, including frequency distributions, percentages, tabular analysis, and inferences for H_0 - H_3 at $p < 0.05$. These were used to assess the levels of policy awareness, adoption of regulatory instruments, and existing waste management practices among stakeholders. The results are presented in tables and discussed in the subsequent section.

Table 2: Population of selected LGAs in the Core Niger Delta

Metropolis (City)	State	Local Government Area	Population in 2006 (NBS, 2013)	Estimated population in 2022	Estimated population by City	Percentage	Number of Questionnaire
Asaba	Delta	Oshimili South	150,032	214,846	214,846	06.08 %	024
Warri metropolis	Delta	Warri South West	116,538	166,882	1,087,913	30.80 %	123
	Delta	Warri South	311,970	446,741			
	Delta	Uvwie	188,728	270,259			
	Delta	Udu	142,480	204,031			
Port Harcourt metropolis	Rivers	Obio-Akpor	462,350	662,085	1,705,658	48.29 %	193
	Rivers	Eleme	190,194	272,358			
	Rivers	Port Harcourt City	538,558	771,215			
Yenegoa	Bayelsa	Yenegoa	*(395,615)	523,794	523,794	14.83 %	060
Total				3,532,211	3,532,211	100%	400

*Estimated population in 2010 for Yenegoa is 395,615

Source: Extrapolated from National Bureau of Statistics, NBS (2013)

Table 3: Schedule of Questionnaire Administered

Stakeholders	Number Administered	Number Retrieved	% of Number Retrieved	Number of Valid Retrieved Questionnaire	% of Valid Retrieved Questionnaire
Regulatory/Monitoring Agencies	36	36	100.00	34	94.44
Distributors/Recyclers/Technicians	90	82	91.11	73	81.11
Consumers/End-Users	274	252	91.97	202	73.72
Total	400	370	92.50%	309	83.03%

Source: Field Survey, 2022

5.0 RESULTS AND DISCUSSION

Following Table 2 representation of the number of questionnaires administered (90), retrieved (82), and valid responses (73), the analysis of respondents is presented in Table A1 and Figure A1. The respondents comprised recyclers, technicians, traders, and importers drawn from selected LGAs in Bayelsa, Rivers, and Delta States. This category represents key operational actors within the solar PV value chain and provides critical insight into the implementation of regulatory frameworks. Beyond descriptive and inferential representations, the distribution of

respondents indicates a concentration of technical and intermediary stakeholders whose activities directly influence waste generation, handling, and compliance with environmental policies.

Table A1: Analysis of the Respondents

Organization/ Occupation	Frequency	Cumulative Frequency	%
Recycler/Technicians/Traders/Importers: Technicians, Traders/Dealers, Scavengers, Recyclers, Refurbishers, etc.	73	107	24
Total	73		100

Source: Field Survey, 2022

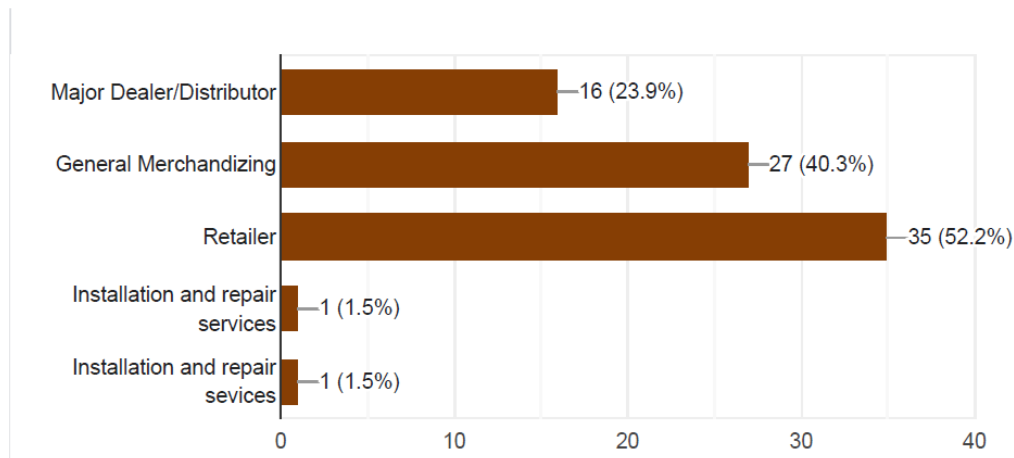


Figure A1: Schema of respondents (Recycler/Technicians/Traders/Importers (67))

The respondents are firms or individuals involved in intermediary activities connected to SPSs acquisition and setups, and who interact with the end-users and regulators under the policy framework deployed for managing wastes from SPSs in the study area. These respondents play a crucial role in the adoption and promotion of management strategies for the afterlife of SPSs in the study area and beyond. We will discuss this framework by first analyzing the applicable guideline(s) adopted and practiced by these respondents and then assessing the strategies deployed for implementation within the Niger Delta region. As a reference, Table 1 listed six (6) national policy instruments approved for use by the government.

5.1 Descriptive Data and Analysis: Waste management policies for solar power systems (SPSs) in the Niger Delta

The data presented in this paper focuses on the applicable guidelines adopted by technicians, recyclers, merchandizers, scavengers, and others in managing decommissioned end-of-life SPSs. The analysis of applicable guidelines (Table B1) reveals not only low levels of awareness but also statistically meaningful patterns in policy adoption. A majority of respondents (63%, 58%, and 67%) indicated no awareness of key regulatory instruments such as the National Environmental (Energy Sector) Regulations (2014), NREEEP (2015), and NEEAP (2016), respectively. Comparative assessment across the six policy instruments suggests that regulations directly linked to general waste management (e.g., the National Environmental Regulations (Electrical & Electronic Sector), 2022 and National Environmental (Sanitation and Wastes

Control) Regulation S.I.28 of 2009) show relatively higher levels of awareness and adoption. This indicates a significant disparity between sector-specific and general environmental policy knowledge, therefore implying weak policy dissemination within an emerging renewable energy sub-sector. These observed distributions further suggest a “positive association between familiarity and operational relevance of regulations”, as stakeholders tend to rather adopt policies perceived as directly applicable to their daily activities. Drawing from the analytical framework adopted in John (2023), such patterns are indicative of weak integration between regulatory provisions and stakeholder practice. The predominance of “not at all” responses across multiple policy instruments suggests a statistically consistent trend of lack of awareness, non-compliance and limited enforcement.

Table B1: Government’s regulations for managing green wastes from solar PV Panel systems by technicians, recyclers, merchandizers and others

Frequency Table: Among the provisions listed below, tick the applicable guideline(s) used by your firm in carrying out routine management of decommissioned solar PV systems:

1. National Environmental (Energy Sector) Regulations, 2014				
	Frequency	Percent	Valid Percent	Cumulative Percent
	not at all	46	63.0	63.0
	very small extent	9	12.3	75.3
Valid	small extent	12	16.4	91.8
	very great extent	6	8.2	100.0
	Total	73	100.0	100.0
2. National Energy Efficiency Action Plan, 2016 (NEEAP)				
	Frequency	Percent	Valid Percent	Cumulative Percent
	not at all	49	67.1	67.1
	very small extent	8	11.0	78.1
Valid	small extent	5	6.8	84.9
	very great extent	11	15.1	100.0
	Total	73	100.0	100.0
3. National Renewable Energy and Energy Efficiency Policy (NREEEP), 2015				
	Frequency	Percent	Valid Percent	Cumulative Percent
	not at all	42	57.5	57.5
	very small extent	10	13.7	71.2
Valid	small extent	9	12.3	83.6
	very great extent	12	16.4	100.0
	Total	73	100.0	100.0
4. National Renewable Energy Action Plan, 2016 (NREAP)				
	Frequency	Percent	Valid Percent	Cumulative Percent
	not at all	40	54.8	54.8
	very small extent	17	23.3	78.1
Valid	small extent	10	13.7	91.8
	very great extent	6	8.2	100.0

Total		73	100.0	100.0	
5. 2022 National Environmental Regulations (Electrical & Electronic Sector)					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	not at all	36	49.3	49.3	49.3
	very small extent	12	16.4	16.4	65.8
	small extent	12	16.4	16.4	82.2
	very great extent	13	17.8	17.8	100.0
	Total	73	100.0	100.0	

6. National Environmental (Sanitation and Wastes Control) Regulation S.I.28 of 2009					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	not at all	27	37.0	37.0	37.0
	very small extent	20	27.4	27.4	64.4
	small extent	12	16.4	16.4	80.8
	very great extent	14	19.2	19.2	100.0
	Total	73	100.0	100.0	

Statistics							
	National Environmental (Energy Sector) Regulations, 2014	National Energy Efficiency Action Plan, 2016 (NEEAP)	National Renewable Energy and Efficiency Policy (NREEEP), 2015	National Renewable Energy Action Plan, 2016 (NREAP)	The 2022 National Environmental Regulations (Electrical & Electronic Sector)	[The National Environmental (Sanitation and Wastes Control) Regulation S.I.28 of 2009	
Valid	73	73	73	73	73	73	73
N	Mis	0	0	0	0	0	0
Mode	1	1	1	1	1	1	1
Range	4	4	4	4	4	4	4
Minimum	1	1	1	1	1	1	1
Maximum	5	5	5	5	5	5	5

Source: Field Survey, 2022

Field observations revealed that where some of these policy instruments were adopted and promoted, it was mostly credited to technicians and engineers involved in the installation, setup, and repair of SPSs, and by other stakeholders, especially in deploying the 5Rs (reduce, reuse, repair, recover, and recycle) principle as part of the management strategies for promoting “cascaded application and second life for end-of-life solar PV devices”. However, 60% of the respondents denied receiving financing mechanisms or rewards for engaging in formal recycling activities with SPSs, as stipulated in the policy implementation framework.

To an extent, these technicians and merchants are consciously aware of and adopt specific state and national regulations in managing these green wastes. Table B2 also provides deviant insight into this. Seventy-one percent (71%) of respondents indicated they are totally unaware or have little knowledge of the relevance of additional national guidelines, such as the Harmful Waste (Special Criminal Provisions) Act Cap H1 LFN 2004 and the National Environmental Protection (Waste Management) Regulations S.I.15 of 1991, in managing emerging decommissioned SPSs in the Niger Delta

The results from Table B2 equally provide further analytical depth on the adequacy and effectiveness of management strategies. A significant proportion of respondents (58%) rated existing regulatory strategies as inadequate, while 73% indicated the absence of defined collection targets and technical guidelines by the states in the Niger Delta to be followed for the management of green wastes from solar devices. This demonstrates a structural weakness in policy design and implementation, which can be interpreted as a limiting factor in achieving environmentally sound management (ESM) of solar PV waste. In addition, over 66% of respondents reported minimal or no adoption of foreign best practices, suggesting limited exposure to global standards adoption.

Table B2: Knowledge of Strategies for managing waste from solar PV Panel systems by technicians, recyclers, merchandizers and others

Frequency Table

1. Are these additional national guidelines – Harmful Waste (Special Criminal Provisions) Act Cap H1 LFN 2004 and the National Environmental Protection (Waste Management) Regulations S.I.15 of 1991 – relevant to decommissioned solar PV systems management domesticated in the Niger Delta?

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid not at all	26	35.6	35.6	35.6
Valid very small extent	26	35.6	35.6	71.2
Valid small extent	9	12.3	12.3	83.6
Valid great extent	8	11.0	11.0	94.5
Valid very great extent	4	5.5	5.5	100.0
Total	73	100.0	100.0	

2. Are the management strategies in the regulatory framework adequate for the effective handling of end-of-life solar PV systems?

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid not at all	26	35.6	35.6	35.6
Valid very small extent	16	21.9	21.9	57.5
Valid small extent	11	15.1	15.1	72.6
Valid great extent	14	19.2	19.2	91.8
Valid very great extent	6	8.2	8.2	100.0
Total	73	100.0	100.0	

3. From the existing national regulations, is there a minimum collection targets and handling expertise defined for the States in the Niger Delta to be followed for the management of wastes from solar devices?

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid not at all	42	57.5	57.5	57.5
very small extent	11	15.1	15.1	72.6
small extent	10	13.7	13.7	86.3
great extent	8	11.0	11.0	97.3
very great extent	2	2.7	2.7	100.0
Total	73	100.0	100.0	

4. Are there provisions in the policy documents that promotes cascaded application and second life for end-of-life solar PV devices?

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid not at all	28	38.4	38.4	38.4
very small extent	20	27.4	27.4	65.8
small extent	16	21.9	21.9	87.7
great extent	8	11.0	11.0	98.6
very great extent	1	1.4	1.4	100.0
Total	73	100.0	100.0	

5. When it becomes necessary, do you adopt any foreign regulations in the management process of solar device wastes?

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid not at all	48	65.8	65.8	65.8
very small extent	13	17.8	17.8	83.6
small extent	3	4.1	4.1	87.7
great extent	4	5.5	5.5	93.2
very great extent	5	6.8	6.8	100.0
Total	73	100.0	100.0	

6. Are there financing mechanisms or reward for formal recycling of solar PV systems included in the integrated policy framework?

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid not at all	44	60.3	60.3	60.3
very small extent	15	20.5	20.5	80.8
small extent	9	12.3	12.3	93.2
great extent	3	4.1	4.1	97.3
very great extent	2	2.7	2.7	100.0
Total	73	100.0	100.0	

Statistics

		3. Are these additional national guidelines – Harmful Waste (Special Criminal Provisions) Act Cap H1 LFN 2004 and the National Environmental Protection (Waste Management) Regulations S.I.15 of 1991 – relevant to decommissioned solar PV systems management domesticated in the Niger Delta?	4. Are the management strategies in the regulatory framework adequate for the effective handling of end-of-life solar PV systems?	5. From the existing national regulations, is there a minimum collection targets and handling expertise defined for the States in the Niger Delta to be followed for the management of wastes from solar devices?	6. Are there provisions in the policy documents that promotes cascaded application and second life for end-of-life solar PV devices?	7. When it becomes necessary, do you adopt any foreign regulation s in the management process of solar device wastes?	8. Are there financing mechanisms or reward for formal recycling of solar PV systems Included in the integrated policy framework?
N	Valid	73	73	73	73	73	73
	Missing	0	0	0	0	0	0
Mode		1 ^a	1	1	1	1	1
Range		4	4	4	4	4	4
Minimum		1	1	1	1	1	1
Maximum		5	5	5	5	5	5

a. Multiple modes exist. The smallest value is shown

Source: Field Survey, 2022

5.2 Inferential statistic and analysis – Significance test of factors influencing SPSs waste management effectiveness: Waste management policies for solar power systems (SPSs) in the Niger Delta

The assessment of policy awareness and waste management challenges of solar PV systems in the Niger Delta, Nigeria (Table B1) revealed low levels of policy awareness among stakeholders. Consequently 4 hypotheses (H₀₁; H₀₂; and H₀₃) were postulated. Thus, we have: H₀₁ “There is no significant relationship between policy awareness and adoption of solar PV regulations among stakeholders”; H₀₂: “Regulatory enforcement has no significant effect on solar PV waste management effectiveness”; H₀₃: “Financial incentives and technical capacity have no significant effect on solar PV waste management effectiveness”. By taking the dependent variable as “Effectiveness of Solar PV Waste Management”, the Independent Variables are “Policy Awareness by stakeholders”, “Regulatory Enforcement”, “Financial Incentives”, and “Technical Capacity for handling SPSs”.

Table C1 presents a multiple linear regression analysis of factors influencing solar PV waste management effectiveness. It offers a guide to the significance test the relationship between the five variables. To provide deeper insight into the determinants of an effective solar PV waste management arrangement, a multiple linear regression analysis was conducted (Table C1). The model explains 50.7% of the variance in waste management effectiveness ($R^2 = 0.507$),

indicating moderate explanatory power. The overall model is statistically significant ($F = 18.392$, $p < 0.001$), suggesting that the selected predictors jointly influence outcomes.

Table C1: Multiple Linear Regression Analysis of Factors Influencing Solar PV Waste Management Effectiveness

Model Summary

R	R ²	Adjusted R ²	Std. Error
0.712	0.507	0.476	0.621

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	28.416	4	7.104	18.392	0.000
Residual	27.801	68	0.409		
Total	56.217	72			

Regression Coefficients

Variable	B	Std. Error	Beta (β)	t	Sig.
(Constant)	1.214	0.332	—	3.656	0.001
Policy Awareness	0.421	0.102	0.438	4.127	0.000
Regulatory Enforcement	0.315	0.118	0.297	2.669	0.009
Financial Incentives	0.287	0.109	0.276	2.633	0.010
Technical Capacity	0.198	0.095	0.201	2.084	0.041

Source: Field Survey, 2022

While Table C2 offers a summary of the variance and interpretations of the outcome (Effectiveness of Solar PV Waste Management) and the predictors/ regressors (Policy Awareness by stakeholders, Regulatory Enforcement, Financial Incentives, and Technical Capacity for handling SPSs). Thus, the regression coefficients shows that policy awareness ($\beta = 0.438$, $p < 0.001$) is the strongest predictor of effective waste management, followed by regulatory enforcement ($\beta = 0.297$, $p = 0.009$) and financial incentives ($\beta = 0.276$, $p = 0.010$). Technical capacity ($\beta = 0.201$, $p = 0.041$) also has a significant but comparatively weaker influence. The inferential interpretation of responses indicates that the low adoption of solar-specific regulations is not random but reflects systemic gaps in governance and institutional communication. These findings also indicate that improving awareness, strengthening enforcement mechanisms, and providing incentives are critical for enhancing compliance and promoting sustainable waste management practices.

Table C2: Interpretation of Regression Results

S/N	Hypotheses	Test Used	Result	Decision	Inference
1	H ₀₁ : "There is no significant relationship between policy awareness and adoption of solar PV regulations"	Regression	$\beta = 0.438$, $t = 4.127$, $p = 0.000$	Reject H ₀₁ ($\beta = 0.438$, $p < 0.001$)	Policy awareness has a strong positive and significant effect on waste management effectiveness.

	among stakeholders”				
2	H ₀ 2: “Regulatory enforcement has no significant effect on solar PV waste management effectiveness”	Regression	$\beta = 0.297$, $t = 2.669$, $p = 0.009$	Reject H ₀ 2 ($\beta = 0.297$, $p = 0.009$)	Regulatory enforcement significantly improves waste management outcomes.
3	H ₀ 3: “Financial incentives and technical capacity have no significant effect on solar PV waste management effectiveness”	Regression	Financial Incentives: $\beta = 0.276$, $p = 0.010$ Technical Capacity: $\beta = 0.201$, $p = 0.041$	Reject H ₀ 3 ($\beta_1 = 0.276$, $p_1 = 0.010$) ($\beta_2 = 0.201$, $p_2 = 0.041$)	Both financial incentives and technical capacity significantly influence effective solar PV waste management, although their effects are moderate compared to policy awareness.

6.0 CONCLUSIONS

The study sought to examine government guidelines for dealing with the value chain of solar power systems (SPSs) in the Niger Delta region of Nigeria. Results revealed a significant gap in awareness and implementation of existing policies among key stakeholders involved in the SPSs value chain. Recyclers, technicians, and traders, despite their crucial role in trading and managing end-of-life SPSs, demonstrated limited knowledge of relevant regulations and guidelines. In particular, the study demonstrates that the challenges associated with solar PV waste management in the Niger Delta are not merely due to the absence of policies but are strongly linked to weak awareness, poor enforcement, and inadequate institutional support. The statistically significant relationships observed reinforce the need for integrated policy interventions that address both governance and stakeholder behaviour. The lack of awareness has resulted in the inadequate management of solar wastes, posing a threat to the Niger Delta’s fragile ecosystem and hindering Nigeria’s sustainable green energy ambitions.

The discussions highlighted the need for enhanced communication and dissemination of existing policies, as well as the development of targeted capacity-building programmes for stakeholders. Furthermore, the study underscored the importance of incorporating extended producer responsibility (EPR) principles and formal recycling into regulatory framework to ensure proper collection, recycling, and disposal of solar PV waste. This would not only mitigate environmental risks but also create economic opportunities in the recycling and repurposing of valuable materials contained in decommissioned solar panels. A concerted effort from both the government and industry stakeholders is crucial to realize the full potential of solar energy in Nigeria while safeguarding the environment.

REFERENCES

- Adeniyi A., Dolapo K., Muriel C., Olufolasewa S. & Uyiosa O. (2020). In review: renewable energy policy and regulation in Nigeria. An extract from The Renewable Energy Law Review, 3rd Edition. *The Law Reviews, Lexology*. <https://rb.gy/fy3p8c>. [Accessed 14th July, 2023]
- Africa Clean Energy Technical Assistance Facility, ACE TAC (2019). *Importation Guide for Solar PV Products and Technologies in Nigeria*. <https://rb.gy/q0b0iq>. [Retrieved 11th May, 2023]
- Africa Clean Energy Technical Assistance Facility, ACE TAC (2021). *E-Waste Guide for Stand-Alone Solar in Nigeria*. Coffey International Development Ltd, United Kingdom. <https://rb.gy/los7ap>. [Retrieved 11th May, 2023]
- Alternative Energy Store Inc (2022). *Components for Your Solar Panel (Photovoltaic) System*. <https://shorturl.at/ctMY4>. [Retrieved 14th June, 2023]
- Benefit O., Suresh S., Surendran and Trevor P. (2014). Impact of Inadequate Urban Planning on Municipal Solid Waste Management in the Niger Delta Region of Nigeria. *Journal of Sustainable Development*. Vol. 7(6). ISSN 1913-9063 E-ISSN 1913-9071.
- City Population (March 21, 2022). *NIGERIA: States & Cities Federal Republic of Nigeria*. <https://www.citypopulation.de/en/nigeria/cities/> [Retrieved 11th August, 2023]
- Donatus A. O., Marianna K. & Vladimir G. (2021). Proliferation of household waste irregular dumpsites in Niger Delta region (Nigeria): unsustainable public health monitoring and future restitution. *Sustainable Environment Research*. Vol 31(4). <https://doi.org/10.1186/s42834-020-00077-1>. [Retrieved 11th May, 2023]
- Emiliano Bellini (2020, February). Italian PV panels destined for recycling were instead smuggled to Syria and Africa. *PV Magazine*. <http://www.pv-magazine.com>. [Retrieved 14th August, 2023]
- Federal Ministry of Power (2015). *National Renewable Energy and Energy Efficiency Policy (NREEEP)*. Approved by FEC for the Electricity Sector. <https://shorturl.at/ltLOY>. [Retrieved 20th February, 2023]
- Federal Ministry of Power, Work and Housing, FMPWH (2016a). *National Renewable Energy Action Plans (NREAP) (2015 – 2030)*. First Version Adopted by the Inter-Ministerial Committee on Renewable Energy. <https://shorturl.at/cpJT6>. [Retrieved 20th February, 2023].
- FMPWH (2016b). *National Renewable Energy Action Plan (NREAP), 2016 (2015-2030)*. Approved by the National Council on Power (NACOP), July 14, 2016. <https://shorturl.at/hsEU7>. [Retrieved 20th February, 2023].
- Institute of Energy Research, IER (2018). *The Mounting Solar Panel Waste Problem*. Article by IER, September 12, 2018. <https://www.instituteforenergyresearch.org/renewable>. [Retrieved 14th August, 2023].
- Institute of Energy Research, IER (2021). *Solar Waste: A Looming Problem*. Retrieved from <https://shorturl.at/hklER>. [Retrieved 14th August, 2023].
- International Renewable Energy Agency (IRENA). (2016). *End-of-life management: Solar photovoltaic panels*. IRENA.
- International Renewable Energy Agency, IREA (2020). *Solar panels are dying, leaving toxic waste*. The International Renewable Energy Agency, IREA. <https://t.ly/aJgk>. [Retrieved 11th August, 2023]
- Isaac Anyaogu (April 6, 2018). New import duty on solar panels: How Nigeria preys on dreams. *BusinessDay*. <https://t.ly/JHbm5>. [Retrieved 11th May, 2023]

- Isaac Anyaogu (February 26, 2018). INVESTIGATION: Nigeria's solar energy revolution stirs toxic battery waste management concern. *BusinessDay*. <https://t.ly/Dv0kH>. [Retrieved 11th May, 2023]
- Jauro, A. (2023, January 23). Nigeria acts to fight growing e-waste epidemic. *Global Environment Facility*. <https://www.thegef.org/newsroom/news/nigeria-acts-fight-growing-e-waste-epidemic>
- John RA., Okorhi OJ., Uhunmwangho R. (2023). A Scientometrics Report on Policies for Managing Decommissioned Solar Power Systems in the Niger Delta, *British Journal of Multidisciplinary and Advanced Studies: Engineering and Technology*, 4(5),1-19. ISSN: 2517-2778 (Online)
- John Richard (2023). *Management Strategies for Handling E-Waste from Solar Devices in selected Cities of the Niger Delta*. (Reg. No. G2022/PHD/METI/CETM/FT/006). [Doctoral Thesis, University of Port Harcourt, River State, Nigeria].
- Krishnan, A., et al. (2022). An overview on recycling of photovoltaic modules at the end of life. *International Journal for Research in Applied Science & Engineering Technology*. <https://www.ijraset.com/research-paper/recycling-of-photovoltaic-modules-at-the-end-of-life>
- LG (2022). *What is a solar power system?* LG Solar FAQs. <https://www.lgenergy.com.au/faq/did-you-know/what-is-a-solar-power-system>. [Retrieved 12th August, 2023]
- Mark Z. Jacobson and Mark A. Delucchi (2010). Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy*, 39, 1154-1169.
- National Bureau of Statistics, NBS, (May, 2018). *2017 Demographic Statistics Bulletin*. National Bureau of Statistics. <https://nigerianstat.gov.ng/download/1241121>
- National Environmental Standards and Regulations Enforcement Agency, NESREA (2009). *National Environmental (Sanitation and Wastes Control) Regulations 2009*. Federal Republic of Nigeria Official Gazette. N0.60 Abuja – 6th October, 2009 Vol.96. Government Notice No. 281. The Federal Government Printer, Lagos, Nigeria. FGP 112/102009/1,000 (0L 54)
- NESREA (2022). National Environmental (Electrical & Electronic Sector) Regulations, 2022. Vol. 109. No. 142 of 2022, Federal Republic of Nigeria Official Gazette No. 50 Lagos – 5th September, 2022. Lagos: The Federal Government Printer, Lagos, Nigeria. FGP186/122022/105. B3451 – 3514.
- NESREA, (2014). *National Environmental (Energy Sector) Regulations, 2014*. No. 141 Lagos - 22nd December, 2014 Vol. 102. Government Notice No. 254. The Federal Government Printer, Lagos, Nigeria. FGP 153/102015/300.
- NESREA. (2022). *National Environmental (Electrical/Electronic Sector) Regulations, 2022*. Federal Republic of Nigeria Official Gazette. <https://faolex.fao.org/docs/pdf/NIG208294.pdf>
- Netherlands Enterprise Agency (2021). *Solar Report Nigeria*. <https://www.rvo.nl/sites/default/files/2021/06/Solar-Report-Nigeria.pdf>
- Netherlands Enterprise Agency (2021). Solar Report Nigeria. Sector Study: Solar Renewable Energy in Nigeria, May 2021. *Netherlands Enterprise Agency* | June 2021 Publication number: RVO-121-2021/RP-INT. <https://www.rvo.nl> [Retrieved 11th August, 2023]
- Ogbuene, E. B. (2014). Sampling techniques and questionnaire distribution in environmental research. *Journal of Environmental Studies*, 8(2), 45–58

- Ogolo, J. I. (2011, December). *Waste management development to protect water resources in the Niger Delta Region*. [WATER AND SOCIETY] WIT Transactions on Ecology and the Environment. Vol 153 (2011). DOI: 10.2495/WS110201
- Okorhi Johnson (2018). *Assessment of Management Strategies for Waste Electrical and Electronic Equipment in South Eastern Nigeria* (Reg. No. G2012/PHD/METI/CETM/FT/013). [Doctoral Thesis, University of Port Harcourt, River State, Nigeria]
- Okorhi O. J., Richard J. A., and Uhunmwangho R. (2023). Policy Framework for Managing Decommissioned Solar Power Systems in the Niger Delta: A Scientometric Report. *ASRIC Journal on Natural Sciences*. 3(1) (2023) 1-17. ISSN 2795-3610 (online), 2795-3629 (print).
- Rahim, N. A., & Mekhilef, Saad (2002). *Implementation of three-phase grid connected inverter for photovoltaic solar power generation system*. Power System Technology, 2002. <https://t.ly/dhfn>. [Retrieved 14th August, 2023]
- Schaltegger, S., & Wagner, M. (2011). Sustainable entrepreneurship and sustainability innovation: Categories and interactions. *Business Strategy and the Environment*, 20(4), 222–237. <https://doi.org/10.1002/bse.682>
- Yamane, T. (1967). *Statistics: An introductory analysis* (2nd ed.). New York, NY: Harper and Row.