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Management of E-Waste Emanating from Use of Solar Photovoltaic Powered Systems at End-of-Life in the Niger Delta Area, Nigeria

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ABSTRACT: There are concerns on the amount of decommissioned solar photovoltaic (PV) power systems devices getting into waste streams but with feeble management strategies in place. This paper evaluated the management of e-waste emanating from the use of solar PV powered systems at their end-of-life in the Niger Delta area of Nigeria using 90 intermediary stakeholders. The findings confirmed that the deployed management strategies were eccentric, inadequate, lacked sustainability and degrades the environment. Respondents were unaware and lack good understanding in applying appropriate management strategies for wastes from decommissioned solar PV power systems. An action framework for executing and enforcement management strategies for these wastes was developed for the study area.

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Solar energy is a low-cost, interminable and reliable energy source from the sun with an increase in energy efficiency (Mark and Mark, 2010). This has been adduced as an implicit solution to problems associated with energy scarcity and insecurity requiring large-scale conversion to clean energy, air and water pollutions from fossils, depleting fossil fuels, climate change, etc. (Africa Clean Energy Technical Assistance Facility, ACE TAC, 2019). Despite the fact that Nigeria has a population of more than 200 million people, with 65% of employable ages, more than 85 million (40%) of its citizens are without access to energy to power their households and businesses (FMP, 2015; Anyaogu, 2018a,b; Atalay et. al. 2021; Netherlands Enterprise Agency, 2021). The Niger Delta, with an estimated population of over 42 million people, is an integral part of Nigeria that is characterized with its rich renewable and non-renewable natural resources, but having grips of squalor, rugged terrain, poverty, poor healthcare services, habitat loss, and environmental degradation (Kimiebi, 2010; Nwogwugwu *et al.*, 2012; National Bureau of Statistics, NBS, 2018; Sahara Reporters, 2022; Harvard International Review, 2022). Such problems therefore calls for innovative solutions. Solar energy generation involves harnessing sunlight with the use of silicon cells. There is no doubt that solar PV panels and backup storages (batteries) are critical to reducing our dependence on harmful conventional power generating fuels from petroleum and coal. But, the quantity of end-of-life solar PV panels from both the public and private sectors has increased by 42% annually since 2010 (ERI, 2021). The problem in its total deployment is dimply "recycling" the old ones at their end-of-life and finite materials needed to manufacture new ones (Institute of Energy Research, IER, 2018; 2021). Regrettably, constitutes of silicon cells in solar PV panels are

particularly reckoned to contribute to solar PV power system waste streams (International Renewable Energy Agency, IREA, 2020). This paper evaluates the management of e-waste emanating from the use of solar PV powered systems at their end-of-life in the Niger Delta area of Nigeria.

MATERIALS AND METHODS

Study Area: The survey was purposely carried out in selected towns in the core Niger Delta – Bayelsa, Delta and Rivers States. This is justified by the importance and high association in generation of wastes from Solar PV power systems and its management.

Table 1: Conceptual framework for "Management Strategies for Handling E-Waste from Solar Devices in Selected Cities of the Niger Delta
Source: John, 2022

	POLITICAL CONTEXT		
ENVIRONMENTAL CONTEXT		*OBJECTIVES*	**SOCIO-CULTURAL CONTEXT**
	Scope (What?)	**PLANNING AND MANAGEMENT** Strategic planning Legal and regulatory framework Public participation Financial management Institutional arrangements Disposal facility Siting	
		SOLAR WASTE GENERATION Solar waste characterisation Solar waste minimisation and source separation	
		SOLAR WASTE HANDLING Solar waste collection Solar waste transfer, intermediate storage, treatment and disposal	
	Proponents (Who?)	**GOVERNMENT AGENCIES** NESREA State Environment Protection Agencies LGA Environmental Health office Nigeria Customs Service Standards Organisation of Nigeria (SON)	
		BUSINESS SECTOR Dealers/Marketers/Retailers	
		INFORMAL SECTOR Technicians/Refurbishers/Scavengers	
		END-USERS Households, Government Institutions, Industries, Private Offices, Trading/Agricultural Businesses, Banks, Educational & Health-Care Centres	
		SUPPORT AGENCIES National Environmental Standards and Regulations Enforcement Agency (NESREA), Abuja Federal Ministry of Power, Abuja European Union Commission, Europe Basel Convention Secretariat, Switzerland	
	Strategic Aspects (How?)	**POLITICAL** Formulation of goals and priorities, Determination of roles and jurisdiction, and Establishment of Legal and Regulatory Framework.	
		INSTITUTIONAL Arrangements and Sectorial Integration	
		SOCIAL Patterns of Solar waste usage, generation and disposal of the population, and the associated Solar waste management needs and demands, End-user participation in Solar waste management activities, and the Ethical issues on Solar waste workers, both formal and informal.	
		FINANCIAL Budgeting and cost accounting systems, Resource mobilisation for Solar waste funding, Cost recovery and operational financing, Cost control	
		ECONOMICAL Impact of Solar waste management services on the productivity and development of the economy, The economic effectiveness of Solar waste management systems, Conservation and efficient use of materials and resources, and Job creation and income generation in Solar waste management activities.	
		TECHNICAL technical planning and design of Solar waste management systems, Solar waste collection systems, Intermediate storage and transfer systems, Solar waste recovery, repair, reuse, recycling and disposal management	
	ECONOMIC CONTEXT		

Collection and Collation of Data: This assessment was demonstrated using investigative research design. The study group comprising stakeholders – end-users, industry (intermediate stakeholders), regulators, among others – (Table 1), are actors playing key roles in the value chain of solar PV power systems. The survey approach was handled through administrated questionnaires. The questionnaires were tailored to ascertain management strategies deployed for wastes from decommissioned solar PV power system devices. The main research question was: what are the management strategies deployed to disused devices from solar PV power system setups?

Processing and Analysis of Data: The data presented were those collected from 90 intermediate stakeholders in 9 LGAs (three from each of the 3 strata of States). The respondents involved are traders, technicians, recyclers/scavengers, assemblers, exporters/importers, manufacturers and distributors of devices for solar PV power systems in the study area. Data were processed using descriptive statistics under linear multivariate regression. Percentile analysis was discussed using collated data in comparison with the existing policy instruments deployed in the study area.

RESULTS AND DISCUSSION

In this section, the management strategies for handling end-of-life devices from solar PV power systems are considered and discussed accordingly. The success of this assessment holds that stakeholders (end-users, industry (intermediate stakeholders), regulators, among others) agree with and have confidence in the prioritised actions (i.e. improved sentiment) and that end-users, technicians/producers/distributors and government stakeholders have co-designed the current policies and have expressed a desire to fully implement them (Okorhi *et al*, 2019). The results presented in this paper are partly drawn from a recent study on "Management Strategies for Handling E-Waste from Solar Devices in selected Cities of the Niger Delta". We adopt Table 1 in presenting the schedule of questionnaire administered to stakeholders in the survey. From the original studies, there were three (3) categories of stakeholders, namely (1) government regulatory/monitoring agencies, (2) distributors/recyclers/technicians, and (3) end-users. However, we present in this paper the field report for category 2 which are the retail traders, recyclers, scavengers, exporters, importers, technicians, assemblers, manufacturers and distributors of devices for solar PV power systems.

Table 1: 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 etc.	90	82	91.11	73	81.11
End-Users	274	252	91.97	206	75.18
Total	**400**	**370**	**92.50%**	**313**	**78.25%**

Source: Field Survey, 2022

In this study, the respondents were investigated on practices adopted in managing generated wastes from decommissioned solar PV power system installations. These are stakeholders playing intermediary roles in the value chain of devices for solar PV power systems through sourcing, sales, distribution, installations of both new and used devices, as well as in the recovery of obsolete devices, repairs, reuse, recycling, source reduction of waste, etc. The questionnaire for this category of respondents was tailored to assess the most appropriate management strategies adopted and deployed in the generation, collection, intermediate storage and final disposal of waste devices from solar PV power systems. These respondents play intermediary roles to either the end-users or owners of installed solar PV power systems and government regulators. There are instances were these respondents communicate feedbacks or connects the consumers and government regulators with the manufacturers of solar PV panel systems devices. The questionnaire elicited mainly basic knowledge on the specific regulations, legislations, laws, acts and guidelines deployed for handling end-of-life solar PV power systems in the Niger Delta. It equally questioned peculiar difficulties that were apparent in the implementation process of the policy framework in the study area.

The field results showed that approved guidelines that govern the management of wastes from decommissioned solar PV power system installations were scarcely known to these respondents. According to 31 (43%) respondents, these legislations remain unfamiliar to them. While 35 (48%) respondents admitted to be knowledgeable to a small extent, only 7(9%) respondents opined they have a good

understanding of the existing regulations for handling wastes from solar PV power system installations in the Niger Delta. Consequently, just 10 (14%) respondents admitted to a great extent in promoting these regulations in the course of their line of business. While 23 (33%) respondents claimed to be adamant, and 40 (55%) posited to a small extent that they promote these waste management regulations. These results is coming from actors that are supposed to be the main promoters of formal strategies, EPR policies, policy instruments involving wastes from solar PV power system installations in the study area. Furthermore, 22 respondents representing about 30% of population surveyed, admitted that the provisions in the National Environmental (Energy Sector) Regulations, 2014 have been an ineffective legislative instrument deployed for the control of hazardous wastes components like disused solar PV panels, end-of-life inverters, spent batteries, etc. in the study area. Another 43 (59%) respondents admitted to a small extent its effectiveness, and only 8 (11%) respondents opined that the provisions in the National Environmental (Energy Sector) Regulations, 2014 are effective for the control of these wastes. The regulations for managing hazardous wastes partly demand that there should be a setup collection designation for hazardous wastes like disused solar PV panels, batteries, inverters, switches, etc. located within a neighbourhood for stakeholders (the end-users and intermediary generators) (Hubka and Eder, 1988; NESREA, 2022). In spite of such stipulations, more than half of the interviewees (42 (58%) respondents) attested that such arrangements were scarce in their vicinities. However, 24 (33%) respondents also submitted that such collection points are sparsely distributed in the study area. From field observations and implication of these respondents, the exclusive collection centres/points for decommissioned solar PV power system devices are practicably inexistence. Rather, observation during the field survey revealed that many of these wastes are managed with informal arrangements and occasionally disposed of using same strategies deployed for general household solid wastes. One of the ways directed by regulators to contain the menace for wastes from decommissioned solar PV power system devices is by providing a policy framework stipulating that manufacturers of solar PV power systems should design components (or redesign used devices) for easy disassembly at their end-of-life (ERI, 2021). Many technicians, merchants and others (17 (23%) respondents) claimed not to have seen significant changes with these devices over a long time. Though, 34 (47%) attested to seeing slight modifications, but then 22 (30%) respondents affirmed to notice major innovations in the designs of devices for the setup of solar PV power systems.

Today, many e-waste recyclers and scavengers pursue material recovery including precious metals. Guidelines for managing obsolete solar PV power system devices comprise pursuit of material recovery and recycling target rates for precious metals and others (NESREA, 2009; 2022). Sixteen (16) (21%) respondents posited that this strategy is yet to gain ground in the study area. However, 51 (70%) respondents slightly agreed that strategies for recovery metals and other have been put in place to recover and recycle disused solar PV power devices. This is in addition to 6 (8%) respondents who strongly affirmed to pursuing material recovery and recycling targets for precious metals and others components. Again, field observations revealed that there are no formal recycling centres in the core Niger Delta. This position could also be deduced from the responses to the posed question – "Do you engage in formal recycling of obsolete solar PV devices?" Here, 16 (22%) respondents disclaimed the practice of formal recycling in the study area. But 50 (68%) respondents agreed to a small extent that formal recycling takes place, while only 7 (10%) respondents strongly agreed that they engage in formal recycling of disused solar PV power system devices. Furtherance to these assertions, the survey revealed that the prominent options from the National Environmental (Electrical/Electronic Sector) Regulation, 2022 deployed as management strategies in the collection, transportation, treatment, storage (intermediate storage), formal recycling and disposal for waste from decommissioned solar PV power devices were primarily Recycling ((32) (44%) respondents) and Repairs ((3) (4%) respondents). Also, respondents deployed other management strategies, including Reuse and Recovery options – 21 (29%) respondents. Again, the claim by respondents on Recycling in study area might be justified as a corroboration of informal recycling that retains footprints in the environment. Another reason that was attributed for respondents' poor adoption of frontier management strategies from the 5Rs, EPR programme, etc. was linked to implementation difficulties in government regulations for managing wastes from solar PV power systems. Sixty four (64) (88%) respondents ascribed one form of difficulty or the other in the implementation process of policy instruments in handling disused solar PV power system devices. Peculiar difficulties noted in the implementation process come from (a) the obsolete technologies and necessary equipment deployed – 54 (74%) respondents, (b) inadequate financing of waste management schemes/ framework – 47 (64%) respondents, as well as (c) the contents of the

guidelines/regulations proffered by government – 30 (41%) respondents. These difficulties were equally reckoned to be impediment for proper recovery, refurbishing and recycling of obsolete devices from decommissioned solar PV power system installations. The obstacles come from: cost implication of setting up a formal recycling firm/centre – 20 (27%) respondents; lack of appropriate legislation and guidelines to support such ventures – 10 (14%) respondents; few stock of devices available for refurbishing – 6 (8%) respondents, as well as; lack of frontier recycling infrastructure – 8 (11%) respondents. In the event of non-compliance with the stipulated guidelines (NESREA, 2022), individuals and businesses were noted to likely face punitive measure of "Imposed fine" – 37 (51%) respondents. In some other instances, defaulters were let loss with "No punitive action taken" – 29 (40%) respondents. Then again, while manufactures of solar PV components are obligated by government regulations to provide essential technical information for handling decommissioned solar PV power systems, the survey revealed that this is not absolutely adhered to this directive. Twenty (20) (27%) respondents admitted that adherence to this stipulation in the study area is impracticable, and 25 (34%) respondents further confirm the implementation to a small extent. On the other hand, 28 (38%) respondents opined that manufacturers of solar PV components do provide essential technical information for handling decommissioned solar PV power systems. But nearly half of the respondents, 35 (48%), also stated that manufacturers of components for solar PV power systems were not practicably compelled to take responsibility for treatment of end-of-life devices based on the concept of extended producer responsibility (EPR), and another 34 (47%) respondents admitting to a small extent the mere concern of manufacturers shown. Besides, the implementation of the EPR programme on disused components from solar PV power systems is apparently invisible. Twenty three (23) (32%) respondents posited that EPR strategies were not implemented at all, and another 38 (52%) respondents acceded that EPR implementation thrives to a small extent in the study area.

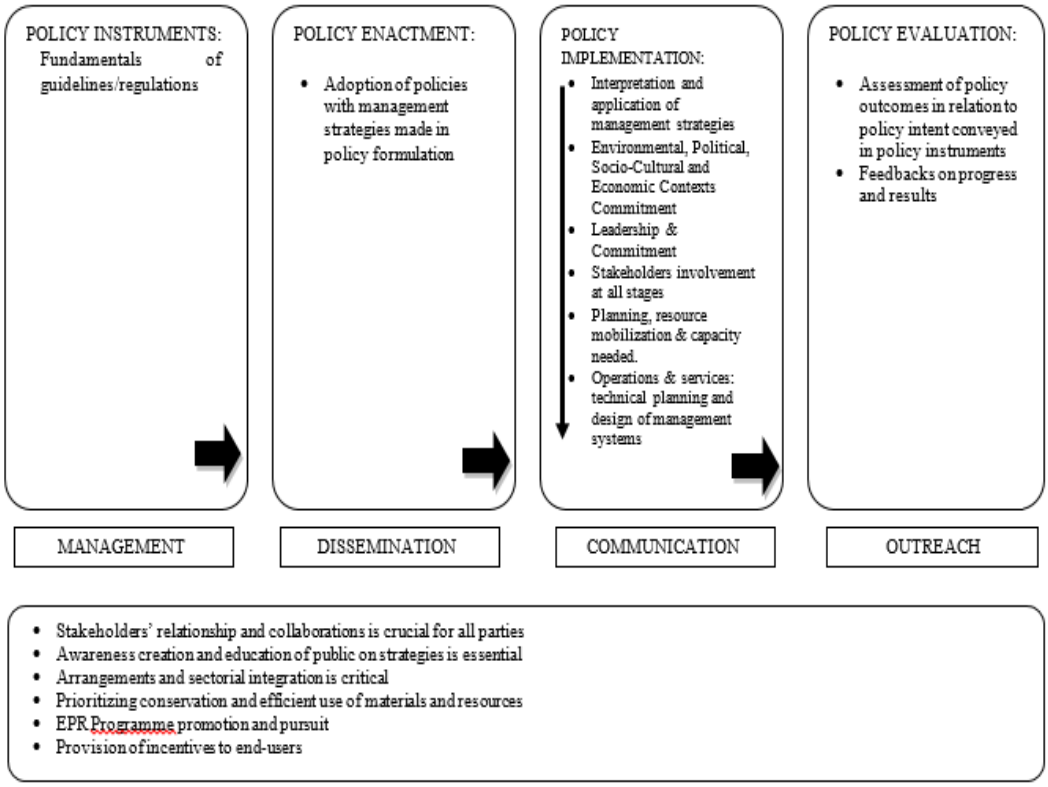

Fig 1: Action framework for executing and enforcement management strategies for wastes from solar PV power systems

According to stipulations in the National Environmental (Energy Sector) Regulations, 2014 and the National Renewable Energy and Energy Efficiency Policy (NREEEP), 2015, the Nigeria government pursues a policy that encourages green investments in renewable energy (FMPWH, 2016a,b)

and energy efficiency in-line with the Kyoto Protocol. Consequently, the government claim to offers potential investors in the renewable energy sector provisions for tax and duty exemptions, fiscal incentives and subsidies to ease upfront costs in their businesses (Federal Ministry of Power, 2015). However, many of the respondents admitted that no form of government incentives or subsidies was received in their businesses to encourage government drive for renewable energy installations across Nigeria. Forty seven (47) (64%) respondents submitted not to have received either incentives or subsidies for getting involved in the value chain activities for solar PV power systems. Another 21 (29%) attested to receiving government support a small extent in their routine businesses. While only 5 (7%) respondents acknowledged affirmative gains from government supports in running their solar PV power system businesses. The latter were mainly merchants who deal on sales of components for setting up solar PV power systems in the Niger Delta. In the core Niger Delta, waste management of decommissioned solar PV power system devices lacks innovation and sustainability, leaving environmental imprints. Current strategies are rudimentary, and key stakeholders are uninformed about best practices like the 5Rs and EPR programme. To address this, the authors suggest a comprehensive action plan (Figure 1) that emphasizes stakeholder education, policy communication, and awareness of policy impacts

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