CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

PV/BATTERY WASTE MANAGEMENT IN THE CONTEXT OF RURAL ELECTRIFICATION

SUPPORT ON PV/BATTERY WASTE MANAGEMENT FOR A RURAL ELECTRIFICATION PROGRAM

Factor
Ideas for change

Document elaborated by Factor
November 2016

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

PV/BATTERY WASTE MANAGEMENT IN THE CONTEXT OF RURAL ELECTRIFICATION

SUPPORT ON PV/BATTERY WASTE MANAGEMENT FOR A RURAL ELECTRIFICATION PROGRAM

Factor
Ideas for change

Document elaborated by Factor
November 2016

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at SciTech Connect http:/www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
OSTI http://www.osti.gov
Phone: 865.576.8401
Fax: 865.576.5728
Email: reports@osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
NTIS http://www.ntis.gov
Phone: 800.553.6847 or 703.605.6000
Fax: 703.605.6900
Email: orders@ntis.gov

Acronyms

AMADER	Malian Rural Electrification Agency
ECREEE	ECOWAS Center for Renewable Energy and Energy Efficiency
ECOWAS	Economic Community of West African States
EPR	extended producer responsibility
EU	European Union
GIZ	German International Cooperation Agency
IDCOL	Infrastructure and Development Company Limited (Bangladesh)
IEA-PVPS	International Energy Agency – Photovoltaic Power Systems Programme
IRENA	International Renewable Energy Agency
OHSAS	Occupational Health Safety Standard
PV	photovoltaic
REREDP	Rural Electrification and Renewable Energy Development Project
R&D	research and development
SBC	Secretariat of the Basel Convention
SHS	solar home system
SWEEPNET	Regional Solid Waste Exchange of Information and Expertise Network
WEEE	waste from electrical and electronic equipment

Table of Contents

List of Figures

Introduction

The waste management of solar photovoltaic (PV) systems in the context of rural electrification presents a great challenge. Systems are, mainly, placed in isolated and underdeveloped areas that are difficult to access, making collection very problematic. But, mainly because nothing is considered a waste in these areas, all components of the PV systems are recycled locally or reused for different purposes.

Another complexity exists because the main components of the system—PV panels, batteries, and eventually lamps (incandescent and compact fluorescents)—demand their own waste management strategy.

PV panels and batteries are entering the waste cycle at different times, panels after more than 25 years and batteries usually in five years; the amount of waste generated is different, and their components need specific treatment to avoid environmental impacts.

In addition, PV panels and batteries have very different starting points in terms of experience in waste management. The waste management industry has experience with recycling batteries (mostly lead-acid) due to their application in vehicles, but this is not the case for PV panels.

End-of-life management could become a significant component of the PV value chain. The recovered material can be injected back into the economy and can serve to produce new PV panels or be sold into global commodity markets, thus increasing the security of future raw material supply. End-of-life management for PV panels will spawn new industries, can support considerable economic value creation, and is consistent with a global shift to sustainable long-term development (IRENA & IEA-PVPS 2016).

At the end of 2015, there were 229 gigawatts (GW) of installed PV worldwide, of which 3 GW are in the Africa and Middle East region (SPE 2016). The amount of off-grid systems is negligible compared with grid connected systems. The few initiatives and studies on PV panel recycling are focused in bigger markets (China, United States, India, Japan, and European Union), which are expecting important streams of PV waste by 2030 and 2050 (IRENA & IEA-PVPS 2016).

Most countries around the world classify PV panels as general or industrial waste. At present, only the European Union (EU) has adopted PV-specific waste regulations. In the EU waste regulation, PV panels fall into the category of electrical and electronic equipment waste (e-waste or WEEE).

E-waste, including PV panels, is of particular concern because it contains hazardous substances (e.g., heavy metals such as mercury and lead, and endocrine disrupting substances such as brominated flame retardants). On the other hand, e-waste also contains materials of strategic value such as indium and palladium and precious metals such as gold, copper, and silver. These materials can be recovered and recycled (SBC 2011).

The major potential environmental concern arising from solar home systems (SHS) is the improper disposal of the lead-acid storage battery used in SHS. If not properly disposed, the lead sulphate can contaminate surrounding land and bodies of water (World Bank 2013). The situation of end-of-life battery management in sub-Saharan Africa is of particular concern. Collection and recycling practices lack basic precaution measures to prevent the emission of lead and battery acid to the workspace and the environment. This causes severe and potentially life-threatening health risks for workers and the communities surrounding such operations (Manhart, et al. 2016).

Battery recycling has a long tradition, both in industrialized and developing countries, especially car batteries. However, the conditions of the recycling process vary dramatically from one country to another.

In developing countries licensed battery recycling plants face a serious competition from the "informal sector." This informal sector consists of battery re-conditioners that replace defective battery cells, and "back-yard smelters," which recover up to about 40% of the lead content of battery cells jettisoned by re-conditioners. In the Philippines, for example, it is estimated that the battery re-conditioners collect almost a third of the domestically generated scrap, while not more than 10% remains uncollected. In India, the formal sector recycles only 20% of the domestically generated scrap (Alsema 2000).

Rapid urbanization, a growing vehicle fleet, and power storage applications (due to the frequent blackouts) are increasing the use of batteries at unprecedented rates in Africa. The total end-of-life volume for lead-acid batteries in Africa is estimated at 1.23 million tons in 2016, which means that every year, more than 800,000 tons of lead require sound management. This amount is equivalent to 8% of the total annual world production of lead (Tür, Manhart and Scheleicher 2016).

Due to the high lead content, used lead-acid batteries have an economic value all over Africa. End-of-life batteries are commonly sold by end users to local scrap dealers for cash. The local scrap dealers sell their batteries to traders who are in contact with wholesale buyers. The increasing volume of batteries and the unbroken demand for lead has spurred the rapid growth of domestic lead recycling industries in many African countries. While, formerly, batteries were often recycled in small backyard workshops, such businesses are increasingly replaced by informal smelters of industrial scale (Manhart, et al. 2016).

Waste Management Stakeholders

The life cycle methodology is a holistic approach to waste management, independent of the type of waste.

The stakeholders of the life cycle of both PV panels and batteries would be producers, distributors, customer, and recyclers. Focusing on the end of the life cycle, the stakeholders could be summarized as follows:

- **Producers:** Part of the waste management process as recipients of recycled material or as the physically and financially responsible party for the environmental impact of their products, through the extended producer responsibility (EPR).
- **Distributors/retailers:** Sell and sometimes install and finance the SHS. They will sell the spare batteries. They are well placed to be part of the waste management chain, doing a preliminary aggregation, but they must be incentivized for that.
- **Consumers:** Responsible for the proper disposal of the battery or PV panel. The consumer may try to minimize costs by, for instance, selling the old battery in the informal market, which can have a negative effect on the development of sound waste collection and treatment.
- **Recyclers:** Formal or informal; profit maximization drives their activity. This activity should be properly counterbalanced by adequate legislation, control, and capacitation to prevent harmful practices, both for them and the general public and environment.

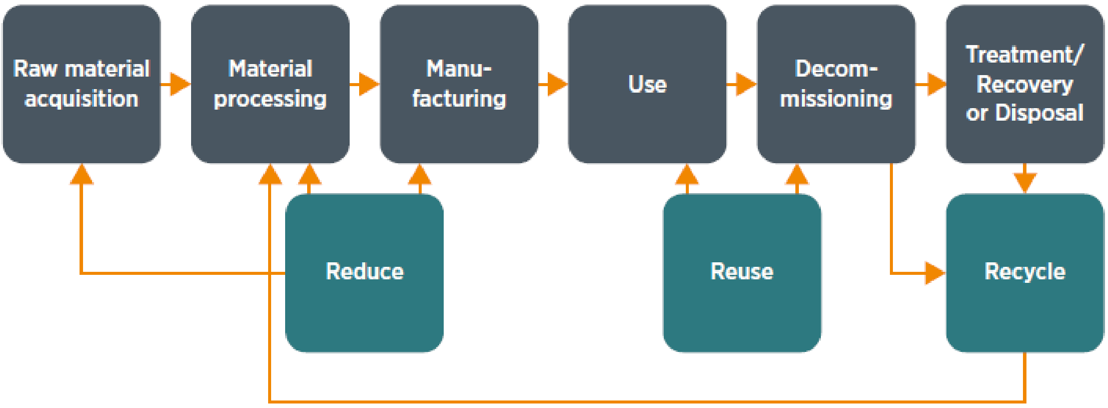

Figure 1. Life cycle stages for PV panels and batteries

Source: IRENA & IEA-PVPS 2016

Waste Management Process

The steps of a recycling process for PV panels and battery components are much the same as any other recycling process, which is composed of the following steps:

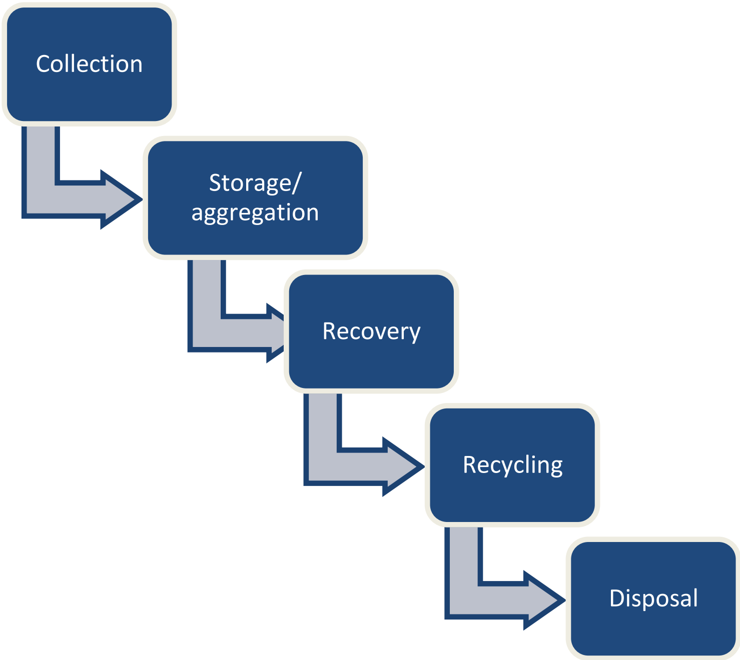

Figure 2. Waste management process for the recycling of PV panels and batteries

In the process, PV panels or batteries are collected from separate waste generation points and transferred to a central location where first-level treatment can start. After this first treatment step, which usually separates the waste product into material groups (e.g., metals, mixed plastics, glass), in the case of PV panels, further processing of the different material streams is required for recovery and recycling. Finally, the disposal of non-recoverable, non-recyclable fractions also needs to be taken care of in the physical system (IRENA & IEA-PVPS 2016).

To what extent this system can be implemented at a local level depends mainly the local technical and financial capacity. It is possible to limit the local activity to the collection and aggregation phase and transfer the classified waste to a broader level (national) with enough capacity to finish the process.

The costs of operating these physical systems are a function of several factors. These include the geographic and economic context, the chosen number of collection and processing points, and the complexity of dismantling and separation processes (first-level treatment). A final factor is the value/costs associated with final processing of the different material streams for recycling or disposal.

Financing Schemes

To provide the financial basis for recycling end-of-life products, several fee models have been developed and implemented worldwide. Part of these fees is set aside to finance the waste treatment system when end-of-life products are dropped off at collection points operated by municipalities, dealers, wholesalers, producers, or their service providers. The fees are typically structured to follow several principles to ensure they are fair, reasonable, based on actual programme costs, and include regular revisions (IRENA & IEA-PVPS 2016).

It is crucial to define which agent would have the fee burden: producers, consumers, or "society" in general:

- **Producer-financed compliance cost:** The producer finances the activities of the waste management system by joining a compliance scheme and paying for its takeback system or stewardship programme.
- **Consumer-financed upfront recycling fee:** The fee is paid to collect funds for the future end-of-life treatment of the product. Consumers pay the fee at the time of the purchase of the panel or the battery. The fee is set according to estimates for future recycling costs but may also be used to offset current recycling costs.
- **Consumer-financed end-of-life fee (disposal fee):** The last owner pays a fee for the collection and recycling costs to the entity in charge of the recycling of the end-of-life product.
- **Society-financed recycling system:** End-of-life management is supported by society, with government organizations controlling and managing operations financed by taxation.

Waste Management Approach

Waste management approaches or schemes need to take into account different options for collection systems (e.g., pick-up versus bring-in systems). They also need to consider the nature and design of products to manage end-of-life and recycling processes adequately (e.g., PV panels are often classified as e-waste). Hence, waste management leads naturally also to a motivation to change the design of products themselves in favor of easier waste treatment, for instance (IRENA & IEA-PVPS 2016).

There are three main approaches for waste management of products like PV panels or batteries:

- **Voluntary approach from producers** that often rely on their internal environmental management systems to manage all of their company's environmental responsibilities, including the end-of-life of their products or services. Within this or other frameworks, some PV panel manufacturers have established individual voluntary takeback or product stewardship programmes that allow defective panels to be returned for recycling on request. The management of such programmes can be borne directly by the company (direct management) or indirectly through a recycling service (indirect management).
- **Public-private approach** is a voluntary scheme that includes both 'bring-in' and 'pick-up' systems based on the principle of a public-private partnership between industry and regulators. An example is PV CYCLE. The association was established by leading PV manufacturers and is fully financed by its member companies so that end-users can return member companies' defective panels at over 300 collection points around Europe.
- **Regulatory approach,** in which regulators establish the producers' legal liability for product end-of-life, the waste collection, recovery and recycling targets, and minimum treatment requirements to ensure environment and human health protection.

Actions for PV Panels/Batteries Waste Management

Cross-sectoral enabling actions are required to establish a long-lasting, self-sustainable and safe waste management system for PV panels and batteries. Actions to create an enabling framework for these systems are (SWEEPNET, 2014):

Institutional Capacity

- Formulate a specific regulation for PV and batteries waste (or as part of e-waste).
- Develop a monitoring and reporting system on waste stream of PV panels and batteries for better informed decision-making.
- Establish an EPR system for entities that import, produce, and market PV panels and batteries.
- Carefully consider the possible roles of the informal collection and dismantling sectors before establishing a parallel system in competition to these structures.

Technical Capacity

- Explore investment and technical transfer opportunities from other sectors (e-waste management and car batteries waste management) for the development of national smelters to process the metal waste locally.
- Explore investment and technical transfer opportunities to create facilities for the recovery of precious and special metals.
- Study and establish the required infrastructure for each stage of the waste value and disposal chain, for example:
    - Collection: Organize business-to-business collection circuits for the public and private sector, business-to-customer circuits for households with door-to-door collection, district waste collection centers, etc.
    - Transport: Encourage the acquisition of vehicles by operators in the existing informal sector through loans at subsidized interest rates, payment facilities, etc.
    - Storage: Facilitate the acquisition of land to build storage for companies, wholesalers, and semi-wholesalers in order to improve storage conditions (more space, specialized zones, competitive rates, etc.). This would mitigate open-air storage and leaching.
    - Dismantling: Organize the informal sector by establishing dismantling cooperatives and offer operators technical and financial support (training, professional equipment, personal protective clothing, etc.)
    - Crushing/mechanical sorting: Develop and disseminate existing technology through technology transfer programs to improve environmental quality.

Human Capacity

- Entities that are currently engaged in informal e-waste and batteries collection and pre-processing become officially acknowledged as key players in the recycling chain.
- Integrate health and safety precautions into informal practices. Offer opportunities for the informal sector to gradually transform itself into a formalized structure.
- Develop outreach, awareness, and education programs and campaigns for consumers on the disposal of PV panels and batteries.

Experiences in Developing Countries

Off-Grid Electrification and its Impacts on the Waste Management System – the Case of Bangladesh (Batteiger 2015)

The SHSs are sold to the end users by so-called Partner Organizations, which provide microcredits as well as the maintenance of the SHS. The Partner Organizations receive financial support and training from the Development Company Limited (IDCOL), while IDCOL receives financial support from the donors. REREDP stands for Rural Electrification and Renewable Energy Development Project.

IDCOL started the SHS program in 2003 to ensure access to clean electricity for the off-grid rural areas of Bangladesh. As of April 2016, about 4 million SHS have already been installed under the program in the off-grid rural areas of Bangladesh. As a result, almost 18 million beneficiaries are getting solar electricity—around 11 % of the total population of Bangladesh. IDCOL has a target to finance 6 million SHSs by 2017, with an estimated generation capacity of 220 MW of electricity (IDCOL 2016).

In the beginning of the REREDP in 2003, no environmental impacts other than CO_2 mitigation were assessed. In 2005, IDCOL developed a policy guideline on the disposal of warranty-expired batteries. Customers should be notified three months before the warranty of five years expires to change their batteries.

In 2006, the Department of Environment of Bangladesh added an amendment to the Environmental Protection Act of 1995, which regulated battery recycling and collection.

Since 2012, regular assessments of environmental impacts of REREDP have to be reported. Despite the guidelines on proper disposal, in the first environmental and social impact report of IDCOL, two major environmental impacts related to the SHS Project were reported: improper disposal of lead-acid batteries and improper disposal of solar panels (Batteiger 2015).

In rural areas, lead-acid batteries are mostly recycled in the informal sector. The reasons for that seem to be that used lead-acid batteries have an economic value and are sold to local recyclers. Customers trust the local recyclers more than the collection framework of the Partner Organizations and, after the warranty time of five years, the Partner Organizations lose their interest in maintaining contact with the customers.

None of the battery recyclers is collecting the batteries with the acids. This mainly happens because of cost savings due to lower weight of the batteries. For this reason, many small-scale collectors drain the acid right after receipt. Most commonly, the acid together with the dissolved and dispersed lead is simply poured out into the environment. This is the first major point of pollution in the recycling chain (Manhart, et al. 2016).

As all international organizations started to ask for environmental impact reports, IDCOL was forced to implement new measures to strength batteries waste management system:

- **Mandatory quality standards for batteries manufacturers**. There are 17 listed battery suppliers in IDCOL SHS program that have fully completed the ISO 14001:2004 (Environmental Management Standard) and OHSAS 18001:2007 (Occupational Health Safety Standard) certification process. Out of these 17 battery suppliers, only three have their own recycling plants, while the rest have entered into arrangements with the existing three recycling plants to use their facilities. Given the growth of the program, the existing recycling capacity will become inadequate in the near future; all the existing manufacturers need to have their own recycling plants. IDCOL will take initiative to require the existing suppliers irrespective of local manufacturers or importers to set-up their own recycling plants by June 30, 2016.

- In order to incentivize consumers to recycle batteries, the Partner Organizations pay the customers a portion of the cost of the new battery as salvage value of the warranty-expired battery of similar capacity. The battery manufacturers then reimburse the salvage value amount to the Partner Organizations on receipt of such batteries (EPR). Subject to availability of funds, IDCOL then pays USD$5 as collection cost to Partner Organizations. As per the guidelines, Partner Organizations do not sell any new battery to the existing SHS customers without collecting the expired ones.

E-waste Africa Programme

The E-waste Africa Programme of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was aimed to enhance the environmental governance of e-wastes and to create favorable social and economic conditions for partnerships and small businesses in the recycling sector in Africa.

The program spanned from November 2008 to until June 2012 and its goal was to enhance the capacity of West Africa and other African countries to tackle the growing problem of e-waste. Specifically, the project aimed to:

- Improve the level of information on flows of e-products and e-waste imported to West African countries and other African countries to enhance decision-making;
- Increase the capacity of partner countries to manage end-of-life e-equipment and e-waste at the national level;
- Investigate the feasibility of establishing environmentally sound materials recovery operations;
- Enhance the capacity to monitor and control transboundary movements of e-waste and to prevent illegal traffic.

The E-waste Africa Programme was carried out in Benin, Côte d'Ivoire, Egypt, Ghana, Liberia, and Nigeria and resulted in reports on the state of e-waste management in each country.

The project was completed with the first Pan-African Forum on E-waste. The Forum adopted a Call for Action on E-waste in Africa, outlining a set of priorities to support development of a regional approach for the legal transboundary movements and the environmentally sound management of e-waste for the African continent to protect human health and the environment as well as to promote opportunities for social and economic development (Secretariat of the Basel Convention 2011).

PV Panel Recycling in China

At present, PV panels in China do not have specific requirements for end-of-life treatment. In February 2009, the State Council promulgated the Waste Electrical and Electronic Product Recycling Management Regulation, which came into effect in January 2011. The 2011 regulation requires e-waste to be collected in various ways and recycled in a centralized processing system. Producers can collect and recycle the products by themselves or entrust collection to sellers, after-sales service agencies or e-waste recyclers and entrust recycling/disposal to qualified institutions. At present, however, PV panels are not included in the waste electrical and electronic products processing directory of the regulation.

Because of the current low volume of waste, China does not have a mature PV panel recycling industry. However, China has sponsored research and development (R&D) on PV recycling technologies, focusing on two recycling methods for c-Si PV under China's National High-tech R&D Programme PV Recycling and Safety Disposal Research from 2012 to 2015.

PV Panel Recycling in India

India has no specific regulations regarding PV panels waste. This waste is covered by general waste regulations. Waste is managed under the 2016 Solid Waste Management Rules and the Hazardous and Other Wastes Rules.

Legislation covering requirements for general e-waste and restrictions on the use of hazardous substances in electronic products are included in the E-waste (Management and Handling) Rules of 2016. However, these rules only apply to household electronics and not PV panels. An industrial-scale e-waste recycling infrastructure already exists in India but only covers household electronics and not PV.

Tender for the Electricity Supply with SHS for At Least 150,000 Isolated Households in Peru

A program for the massive deployment of SHS has been launched in Peru. It has been estimated that there are around 500,000 households that could potentially benefit from the program. Providing these users with an SHS would be a significant contribution to close the energy access gap. This has resulted on the first tendering for energy supply for off-grid zones with SHSs for at least 150,000 households. The tender process started in September 2013 and the contract was signed in November 2014. Implementation started only recently because the result of the tender was challenged. The Tender documents address waste management as follows:

> *The investor (winner of the tender) is obliged to commit with all applicable Laws, among others the Peruvian Standard Norms for the management of waste for the components of the systems, as well as, all norms related with the environment, quality, security, social and labour among others.*

There are technical norms and regulations in Peru for electronic equipment, but those explicitly exclude equipment for electricity generation. While the other components of the system could be considered under these norms, it is not clearly the case for the PV panels.

ECREEE-AMADER Project Pre-Feasibility Study of the Hybridization of 97 Rural Minigrids in Mali

A tender to procure a study was launched in January 2016 by the ECOWAS Center for Renewable Energy and Energy efficiency (ECREEE) and the Malian Rural Electrification Agency (AMADER) that includes the drafting of an Environmental Management Plan for the hybridization, with PV, of existing diesel mini-grids. Initially, this study should include guidelines to address waste management.

Conclusions

With the large-scale deployment in recent years, there is an increasing concern about the environmental and health impact of waste management of the different components of solar systems.

The waste management of PV systems in the context of rural electrification presents a great challenge. Systems are, mainly, placed in isolated and underdeveloped areas that are difficult to access, making collection very problematic. But, mainly because nothing is considered a waste in these areas, all components of the PV systems are recycled locally or reused for different purposes.

The Africa and Middle East region has only 1.3% of worldwide PV installed capacity. The amount of off-grid PV systems is negligible. Today, most countries around the world classify PV panels as general or industrial waste. While there is a clear business opportunity in the PV panels waste management sector, this seems to be the case mainly in a few big markets.

Battery recycling—especially car battery recycling—has a long tradition, both in industrialized and developing countries. Due to the high lead content, used lead-acid batteries have an economic value all over Africa. End-of-life batteries are commonly sold to local scrap dealers for cash. The local scrap dealers sell their batteries to traders who are in contact with wholesale buyers. The increasing volume of batteries and the unbroken demand for lead has spurred the rapid growth of domestic lead recycling industries in many African countries. While, formerly, batteries were often recycled in small backyard workshops, such businesses are increasingly replaced by informal smelters of industrial scale.

While there are not international experiences on rural electrification programs with a ful-fledged waste management system in place and working properly, some lessons learned and best practices on waste management could be applied to PV systems for rural electrification:

- The first pillar of any waste strategy is prevention. The inclusion of quality standards all along the value chain, and in particular to producers, will better protect people and the environment and will extend the life of panels and batteries, reducing the waste.
- Carefully consider the possible roles of the informal collection and dismantling sectors before establishing a parallel system in competition to these structures.
- Formulate specific regulation for PV panels within the legislation on waste of electrical and electronic equipment.
- Formulate waste management guidelines for the rural electrification program.
- Establish a prequalification system for organizations willing to participate in the rural electrification program. To qualify for the rural electrification program, staff from the organizations will have to complete training in, among other topics, waste management.
- Establish a buy-back mechanism, particularly for batteries, by introducing financial incentives/rewards for households to return expired batteries to the prequalified organization rather than to informal smelters.
- To finance the buy-back mechanism, establish an extended producer responsibility system for entities that import, produce, and/or market PV panels and batteries.

Bibliography

Alsema, E.A. Environmental Life Cycle Assessment of Solar Home Systems. Utrecht: Department of Science Technology and Society. Utrecht University, 2000.

Batteiger, Alexander. "Off-Grid Electrification and its Impacts on the Waste Management System the Case of Bangladesh." 2015.

IDCOL. IDCOL. 2016. http://idcol.org/home/solar (accessed 11 17, 2016).

IRENA & IEA-PVPS. End-of-Life Management: Solar Photovoltaic Panels. 2016.

Manhart Andreas , Amera Tadesse, Kuepouo Gilbert, Mathai Diana, Mng'anya Silvani, and Schleicher Tobias. The deadly business – Findings from the Lead Recycling Africa Project. Freiburg: Oeko-Institut e.V, 2016.

SBC. Where are WEee in Africa? Findings from the Basel Convention. E-Waste Africa Pogramme. 2011.

Secretariat of the Basel Convention. Basel Convention. 2011. http://www.basel.int/Implementation/Ewaste/EwasteinAfrica/Overview/tabid/2546/Default.aspx.

SPE, Solar Power Europe. "Global Market Outlook for Solar Power 2016 - 2020." Brussels, 2016.

SWEEPNET. Report on the Solid Waste Management in Morocco. GIZ, 2014.

Tür Maria, Manhart Andreas, and Scheleicher Tobias. Generation of used lead-acid batteries in Africa - estimating the volumes. Freiburg: Öko-Institut e.V., 2016.

World Bank. "Implementation completion and result report. Rural Electrification and Renewable Energy Development Project. The People's Republic of Bangladesh." 2013.