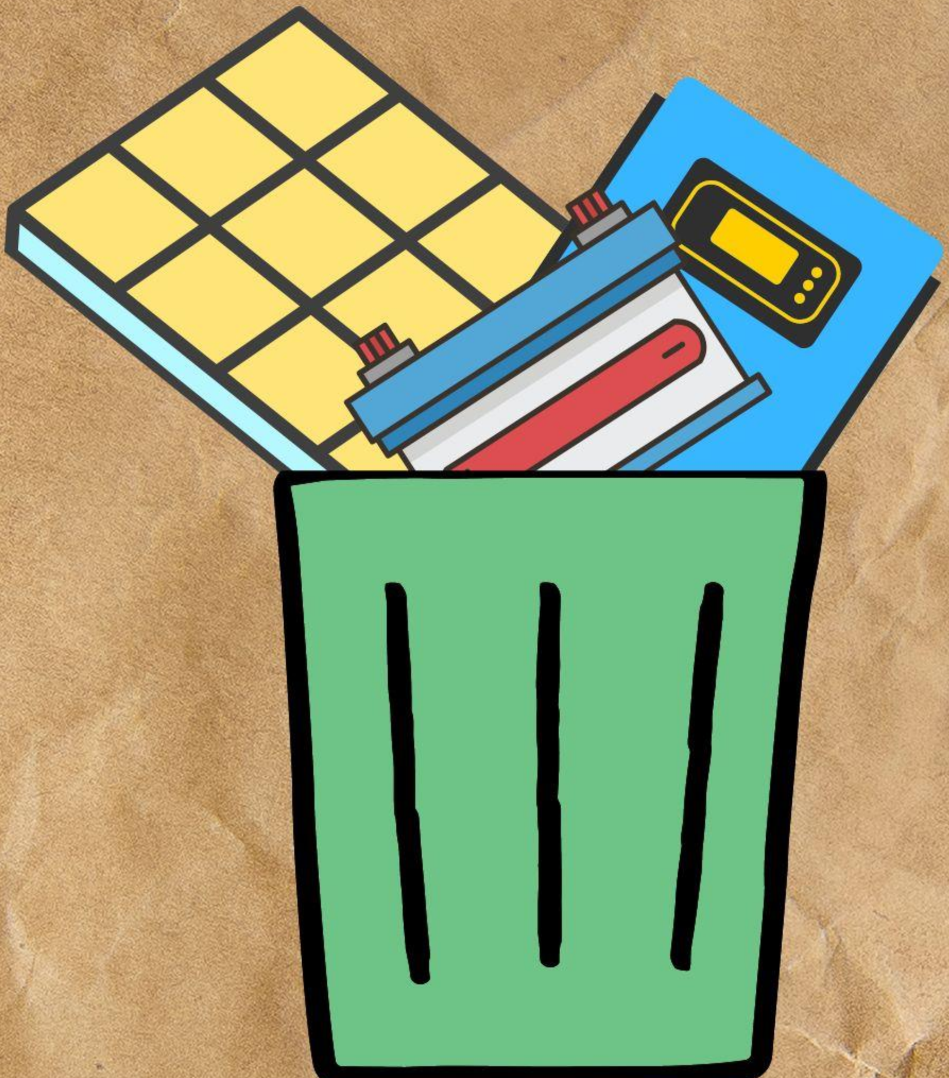
A review of electronic and solar PV waste management in Nepal



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Acronyms

AC	Alternating current
AEPC	Alternative Energy Promotion Center
EEE	Electrical and Electronic Equipment
EoL	End of life
EPA	Environment Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
GW	Gigawatts
HS	Harmonized system
kW	Kilowatt
kW	Kilowatt-peak
Mt	Million metric tons
MT	Metric tons
NEA	Nepal Electricity Authority
NEPCEMAC	Nepal Pollution Control and Environment Management Centre
NGO	Non-governmental organization
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
POP	Persistent organic pollutant
POSTED	Promotion of Solar Technologies for Economic Development
PV	Photovoltaic
RoHS	Restriction of Hazardous Substances
SHS	Solar home system
VRLA OPzV	Valve regulated lead acid battery, Ortsfest (stationary) PanZerplatte (tubular plate) Verschlossen (closed)
WEEE	Waste Electrical and Electronic Equipment

1 Introduction

Promotion of Solar Technologies for Economic Development (POSTED) is a solar PV-focused programme with three wings of support; i) policy and regulation, ii) capacity development and iii) monitoring. Under the monitoring wing, POSTED aims to support solar PV e-waste monitoring in Nepal. This report emerged as an assessment to understand the e-waste and more specifically the landscape around solar PV e-waste in Nepal. This assessment will then assist in the monitoring of solar PV e-waste.

Electrical and electronic equipment have become a part of humankind's opulent living as a result of rapid advances in science and technology, economic expansion, and enhanced lifestyle. Electronic devices have spread throughout the world's markets and their use has increased exponentially.

Worldwide, the term Electrical and Electronic Equipment (EEE) after the end of their useful life is referred to as Electronic Waste (also known as E-waste) (EPA, n.d.; EU, n.d.). This is one of the most rapidly increasing wastes in the municipal waste stream. Waste Electrical and Electronic Equipment (WEEE), is another often-used abbreviation for e-waste.

Several factors, including the development of technology, rising demand for and penetration of EEE, shorter life expectancies and a faster rate of obsolescence contribute to the increase in the volume of e-waste in municipal solid waste streams. When an electric or electronic product reaches its end-of-life (EoL), its original consumer is no longer satisfied and thus, the product is categorized as e-waste.

According to reports, over 50 million tons of e-waste is generated globally, with Asia alone accounting for 12 million tons (Forti et al., 2020). E-waste accounts for 1-3% and 1-2% of total municipal waste in global and developing countries respectively.

The deployment of solar PV has seen a rapid increase since the beginning of this century. At the end of 2021, the capacity of globally installed PV reached 849 gigawatts (GW). This rise in solar PV installation can be accounted for the growing concerns about climate change, the health implications of air pollution, energy security, and energy accessibility(Renewable Energy Agency, 2022).

The increase in installation consequently increases the volume of decommissioned PV systems. The global PV waste was estimated to reach 43,500-250,000 metric tonnes by the end of 2016. The cumulative waste volume of PV is forecasted to reach about 60-78 million tons, with China accounting for 20 million tons followed by the USA with 10 million tons at the end of 2050(IRENA and IEA-PVPS, 2016).

This unprecedented growth of solar PV waste raises a new environmental challenge. E-waste management done right may benefit the environment as well as provide a potential resource for recovering key elements, which might be economically beneficial.

1.1 Objectives

The goals of this study are to close the knowledge gap caused by the lack of adequate studies in the area of e-waste in Nepal. The objectives of this study are:

i. To explore current methods for managing and estimating e-waste to determine the scope and process involved in e-waste management and recycling in global as well as national contexts.
ii. Conduct interviews with waste management companies to learn about their current waste and e-waste management practices, identify key issues which may present opportunities or warrant attention and identify limitations and challenges in Nepal, such as access to processing technology, scale, and economic feasibility.
iii. To investigate an experimental solar PV e-waste projection approach and offer estimates of solar PV e-waste volumes per year by extrapolation, which can assist Nepalese institutions in monitoring solar PV e-waste and, eventually, e-waste management.

1.2 Scope

Nepal is facing various waste management challenges and has no specific guidelines for the collection and management of e-waste. To assess the scope of the problem and build a management system, research on present management procedures (national and international) and estimation of e-waste is necessary. This study aims to establish a reference point in the field of e-waste management with a particular focus on solar PV e-waste monitoring.

This study will explore the policies and methods of e-waste management of industrialized countries and countries in South Asia. Then, the focus will narrow down to Nepal's e-waste predicament and the current state of solar e-waste in Nepal. Building on the current status, an experimental solar PV e-waste projection and monitoring method will be described.

The method described in this report exposes gaps and challenges that need to be strengthened to have reliable national e-waste monitoring in place in the future. The method described, however, does aim to inform the direction in which the e-waste management priority should be set for certain solar PV e-waste components.

1.3 E-waste context

Any electrical equipment has a lifecycle. EEE has a life cycle that begins with its manufacture and ends with EoL management as shown in Figure 1. Before manufacture, raw materials necessary for manufacturing are counted in their life cycle, which includes mining and processing of raw materials. Any product will be used by its prospective user once it has been manufactured, which might be households, factories, offices, business institutes, or any other institution.

The product may be stocked by the user for a specified duration. The quantity of WEEE in its EoL is affected by the duration of time a user stores any product after using it. EEE becomes WEEE after being discarded by its users, and then enters the phase of EoL management.

The primary goal of EoL management is to recover valuables from WEEE and to handle hazardous and toxic substances that cannot be recovered and are created during the recovery process in an ecologically sound manner. In Figure 1, the term discarded refers to resources that cannot be retrieved and disposed of in landfills while hazardous substances will have been safely treated. Materials that are recovered are subsequently employed as secondary resources in new product manufacture. The alternative option for EoL management is to reuse the equipment, which may be accomplished by repurposing discarded EEE or by repairing the equipment.

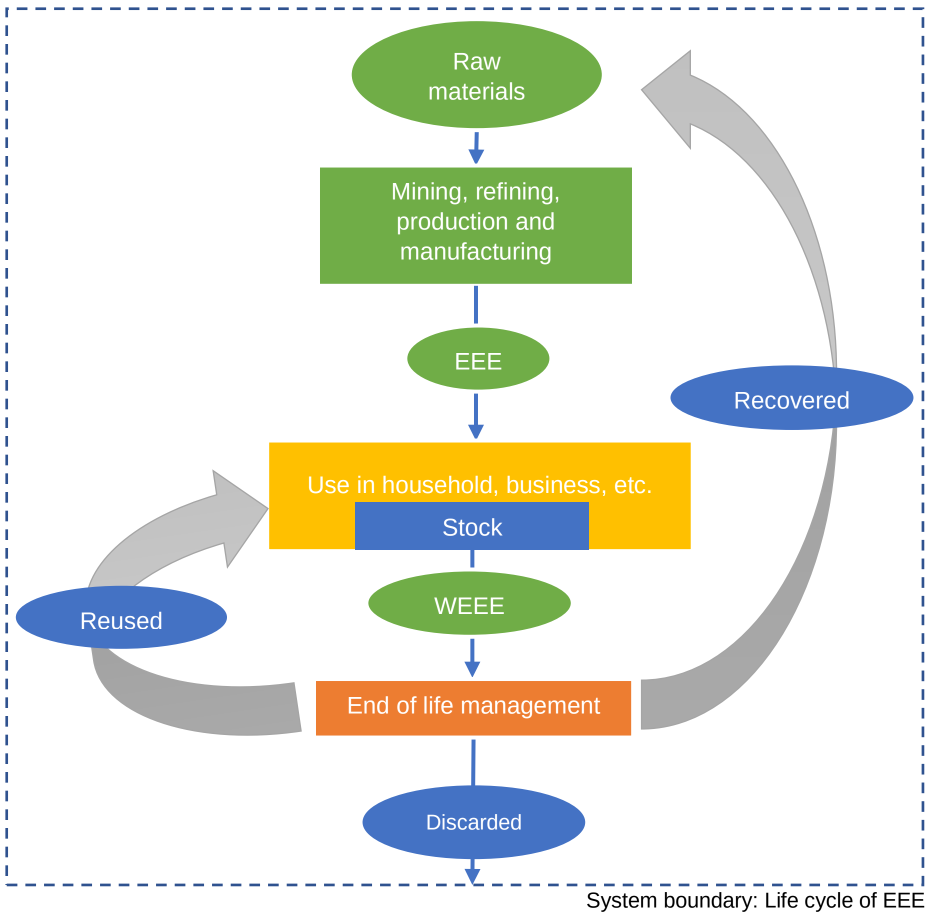

Figure 1: Simplified illustration of the life cycle of EEE

The ultimate fate of any waste is disposal either in landfills or by incineration. Thus, for safe and environmentally friendly e-waste management, the first step would be to create a model to quantify future e-waste.

2 Global situation of e-waste management

The global increase in electrical and electronic equipment production and use has been exponential in the previous two decades. This is primarily due to increased product market penetration in developing countries, the development of a replacement market in developed countries, and the generally high rate of product obsolescence. The amount of WEEE produced in 2019 globally was roughly 53.6 million metric tons (Mt) or 7.3 kg per person. The quantity of e-waste created is expected to surpass 74 Mt by 2030. As a result, the global amount of e-waste is growing at an alarming rate of nearly 2 Mt per year (Forti et al., 2020).

In 2019, the formally documented collection and recycling of e-waste were just 9.3 Mt or 17.4% of the total worldwide waste. It has grown by 1.8 Mt or around 0.4 Mt each year. During the same period, however, total e-waste output climbed to an annual growth rate of about 2 Mt. This illustrates that recycling measures are lagging globally, while e-waste is increasing(Forti et al., 2020).

When analysing the issue of e-waste management, the key factors that are highlighted around the world are international as well as national laws, distinct management approaches, and, last but not least, the quantification of e-waste generation and its estimation. This section delves into all three components of e-waste management, as well as the global solar PV e-waste situation.

2.1 International legislation and standards

International and national e-waste policies are developed by nations all over the world to address the rising WEEE problem. Many of the policies establish non-binding frameworks or courses of action to present a big picture of what society may achieve if they efficiently control e-waste. Table 1 summarizes some of the international legislative frameworks signed by various nations to govern and control WEEE.

Table 1: International legislation and standards on e-waste

Name	Year signed	Number of countries that signed	Main principle
The Basel convention	1989	190	Extended producer responsibility (EPR)
The Rotterdam convention	1998	161	Prohibition of harmful pesticides and chemicals in industries
The Stockholm convention	2001	186	Eliminate the use and generation of persistent organic pollutants (POPs)
EU's WEEE Directive and RoHS	2003	Standard applicable for EU countries	Extended producer responsibility and prohibit the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) by percentage weight
The 3Rs and StEP	2004	Globally accepted standards	Reduce, Reuse, and Recycle

As of October 2019, 78 countries have an e-waste policy, legislation, or regulation in place. These currently cover 71% of the world's population. This is a 5% rise from 66% in 2017. However, the coverage rate might be misleading since it can be misinterpreted as little left to do in terms of regulating e-waste management. In many countries, policies are non-legally enforceable, but simply programmatic initiatives. For example, in Africa and Asia, there are 19 nations with legally binding e-waste laws, 5 countries with an e-waste policy, but no legally enforceable legislation, and 31 countries with a policy under development.

The best policy or regulatory framework in the world is useless unless it sets attainable goals and is successfully implemented. Unfortunately, this is far too frequently not the case. In many nations, the overall e-waste management system is either not adequately funded or not funded at all.

2.1.1 E-waste legislation in selected countries

i. Switzerland

Switzerland has been a pioneer in e-waste management regulations. In 1998, the Swiss Federal Office implemented an E-waste management process through the "Ordinance on the Return, Taking Back, and Disposal of Electrical and Electronic Equipment". Producer responsibility organizations had already formally started the project for WEEE collection and management before the legislation came into effect (Oliveira et al., 2012).

Switzerland established its legal and administrative framework on the extended producer responsibility model, under which producers and exporters bear the material and monetary costs of environmentally sound e-waste treatment, recycling, and disposal (Wäger et al., 2011).

ii. Sweden

Sweden established its WEEE management strategy in July 2001 to ensure that WEEE is appropriately handled. Consumers may now exchange their old EEE for similar new ones at stores (old-for-new or new-for-old rule).

Institutional and commercial users must pay for the treatment of their WEEE; however, residential customers can dispose of their WEEE at municipal collection locations. These WEEE collection facilities for residential users are operated by municipalities, and manufacturers are responsible for covering the costs of WEEE collection and treatment (Sasaki, 2004).

iii. USA

In the United States, the Environmental Protection Agency (EPA) is endeavouring to educate customers about the benefits of reusing and recycling electronics, as well as the options for doing so safely. More than 20 states have approved legislation to control WEEE based on the extended producer responsibility principle, and more are expected to follow suit (Lundgren, n.d.).

According to the US EPA, between 2003 and 2005, 80% to 85% of the e-waste that was prepared for end-of-life treatment ended up in US landfills. In terms of e-waste management, structural development and collection systems, the United States lags behind other developed nations. Few states, like California, are highly advanced, and many businesses are working on e-waste collection, recovery, and reuse (Kahhat et al., 2008).

iv. Japan

Japan established WEEE management legislation in April 2001 to handle and recycle four major electrical equipment wastes, including air conditioners, televisions, laundry equipment, and refrigerators. It is required that the retailers and the consumers collaborate to ensure the collection of WEEE. There is a requirement for the consumers to agree on a "recycling tax" levied as a pre-treatment price (Sasaki, 2004).

Furthermore, there are two options for the industrial and commercial users for handling WEEE. Either user send it to retailers with the pre-treatment fee or treat it as industrial waste at their own expense. Retailers are required to accept approved WEEE from the consumers and send it to manufacturers at designated collection locations (Sasaki, 2004).

v. India

In terms of e-waste processing, India is second only to China. India alone produces 400,000 tons of e-waste on an annual basis. For example, Bangalore processes more e-waste than it produces domestically (Borthakur, 2015).

The "Municipal Solid Waste Management Laws" from 2004 and the "Hazardous and Waste Management Rules" from 2008 are two sets of rules and regulations issued by the Ministry of Environment and Forests for waste management that have an impact on e-waste in India (Manomaivibool, 2009).

In 2012, new and more detailed restrictions known as the "2010 E-waste Management and Handling Rules," came into force. These established the limit for hazardous substances such as lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ethers, also known as the six Restriction of Hazardous Substances (RoHS) materials. The import of e-waste into India is prohibited, according to a judicial order. The restrictions' impact on the informal recycling sector, or the unlawfully imported e-waste each year, is likely to be minor.

vi. China and other developing nations

China banned 21 different categories of e-waste on July 3, 2002. Despite this, China is now the world's top supplier of EEE as well as the major buyer of WEEE (Yu et al., 2010). Once the e-waste reaches China, the majority of the dismantling is done manually or using outdated techniques in workshops. Even though they are exceedingly detrimental to the environment, especially water resources, practices of open burning, and acid baths are popular in China (Bo & Yamamoto, 2010). The government has just recently adopted legislation and created infrastructure on WEEE and RoHS following EU requirements and there is presently no uniform collection system for domestic e-waste. As a result, household collection rates have grown, even though, under the WEEE guideline, customers must pay an extra price for recycling (He et al., 2006).

2.2 Global current e-waste management practices

Different techniques of e-waste management are in place in various regions of the world, with varying laws and regulations. They can, however, be classified for easier comprehension. A study categorized the various practices adopted by nations around the world for e-waste management into four scenarios (Baldé et al., 2017). Table 2 depicts how management systems may be classified into four distinct approaches, from most desirable to least desirable.

Table 2: Management systems are categorized into four main practices

Main practices	Description	
Official take-back system	Typically seen in industrialized nations where e-waste is collected directly by municipalities, retailers, or commercial pickup services and then shipped for further processing in various recycling centres.	Most desirable
Collection outside the official take-back system	This method is generally seen in developed countries, where e-waste is collected by individual waste dealers or companies and then delivered to metal recycling, plastic recycling, or exported.	
Informal collection and recycling	Most frequently seen in underdeveloped nations, where e-waste is collected and recycled by independent workers. The collection is generally done door-to-door by untrained individuals. If the gathered waste has little value, it is disposed of in a landfill or incinerated, causing significant environmental harm and posing substantial human health hazards.	
Disposal with mixed residual waste	This system is particularly common in underdeveloped nations, where e-waste is disposed of with domestic wastes in landfills or incinerated, with little prospect of separation. In the end, it all adds up to hazardous leaching in a landfill or dangerous air emissions if burned.	Least desirable

2.3 Estimating the e-waste quantities

It is necessary to forecast the amount of waste that will be generated in the future to design suitable policies for e-waste management and address various challenges in separation, recycling, and disposal. Most of the time, information on the creation or collection of e-waste in various countries is insufficient due to a lack of data and projection of potential e-waste.

Monitoring and estimating e-waste volumes and flows is critical for analysing trends to define and track goals. Better e-waste data is required to inform appropriate policies and legal frameworks. Quantifying e-waste and tracking its deployment offers a foundation for monitoring, managing, and eventually preventing illegal transport, dumping and inappropriate treatment of e-waste. Accuracy in e-waste estimate and forecasting is thus essential to determine the scale of the problem and make appropriate strategies and regulations.

There are no precise methodologies outlined for calculating the overall quantity of WEEE generated. Varied methods have been employed worldwide to estimate the amount of WEEE produced. The approaches have been developed to estimate e-waste generation, collection and recycling of domestic and transboundary movement. A study done by Kumar et al. categorized four different techniques that are generally used in e-waste estimation. Table 3 gives an overview of the four major methods used for the estimation of e-waste generation.

Table 3: Methods of estimating e-waste generation

Approaches	Description	
Hybrid sales obsolescence-trade data method	This is a modified sales obsolescence method approach that estimates generation using sales and survey data, collection rate using survey data, and export using detailed trade data. This technique is more thorough since trade statistics for all sorts of electronics are easily available for each year and also offer forecasts for the future, including the destination country.	Most accurate
Sales obsolescence method	This model is based on survey sales statistics and electronic lifespans, as well as trends in collection rates. The sales data for an area over time is gathered, and the lifespan of an electronics product is evaluated based on usage, storage, and reuse data acquired from the survey throughout time. The waste creation is then predicted using sales data and lifespans.	
Survey scale-up method	It quantifies the generation and collection of e-waste in a region using survey and census data. Scaling factors are used to provide estimates at the national level. The data from the regional level is used to scale up the estimations for the national level. This is accomplished by comparing the national population to the population sampled.	
Mass balance method	This approach quantifies electronic flows by extrapolating survey data. It enables the estimation of several utilized electrical items at the same time with fewer data inputs. Exports are estimated using mass balance, therefore there is greater uncertainty, and the export destination cannot be defined.	Least accurate

2.4 Global solar PV e-waste

Solar PV technology adoption has increased considerably in recent years. PV provides cost-effective and environmentally beneficial power generation, but like any technology, it degrades and must eventually be decommissioned (which includes dismantling, recycling and disposal). The number of solar panels entering their end-of-life stage will increase continuously with the increased installations. When the useful life of solar PV systems comes to an end, the solar PV system will turn into a type of hazardous waste and, if not recovered or disposed of correctly, could harm the environment.

Proper management of solar PV systems that are approaching their end of life is increasingly crucial for the environment. Therefore, with the increase in installations and expansion of production, it will increasingly become more important to recycle PV system waste properly (Sanchita Tasnim et al., 2022).

2.4.1 Global solar e-waste volume projections

The global solar PV waste was estimated to be 43,500-250,000 metric tons by the end of 2016. This represents only 0.1% to 0.6% of the total mass (in million tons) of solar panels. It is projected that solar PV waste will reach around 8 million tons in 2030 and about 60-78 million tons by 2050 as solar PV installation grows(IRENA and IEA-PVPS, 2016).

Figure 2 summarizes the global projection of PV panel waste volume based on present and projected yearly installations. By 2050, discarded PV systems might account for 60 to 78 million tons (10% of all e-waste produced) globally.

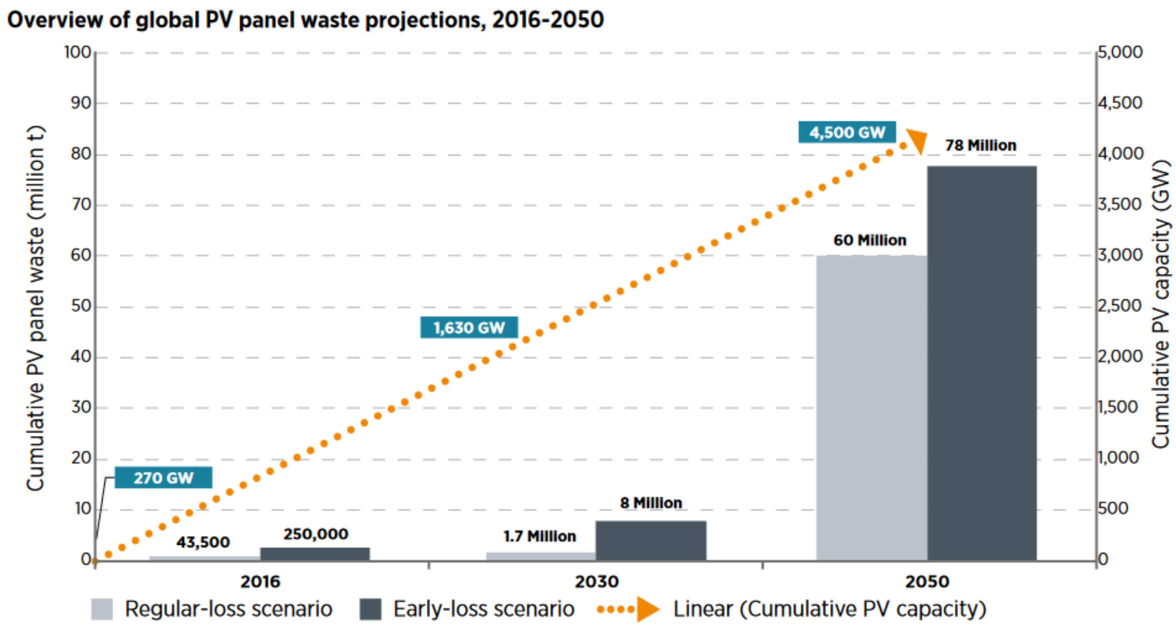

Figure 2: Global solar PV projection, image source (IRENA and IEA-PVPS, 2016)

2.4.2 Solar PV system waste classification

Waste regulations are based on waste categorization. This categorization is determined by the waste's composition, notably any hazardous components. Waste categorization tests establish which wastes can and cannot be shipped, treated, recycled, or disposed of. The scope of this report does not allow for a complete assessment of the considerably variable global PV waste categorization. Instead, this section describes the components found in PV systems as well as waste classification considerations. In the absence of additional, more precise waste categories and standards, Figure 3 identifies the necessary paths for solar PV system treatment and disposal.

Figure 3 gives a detailed description of the waste composition from solar PV system e-waste. The major components of an off-grid solar product are solar panels, batteries (lithium-based or lead acid), control units with circuit-board-mounted electronic controllers, wiring, metal frames, and fixtures. After the end of their useful life, the components of the off-grid solar PV system are divided into groups based on how easily they can be treated and disassembled. Each category of waste is referred to as a fraction, for example, metal, glass, plastics, paper and cardboard, and cables (GOGLA, 2019).

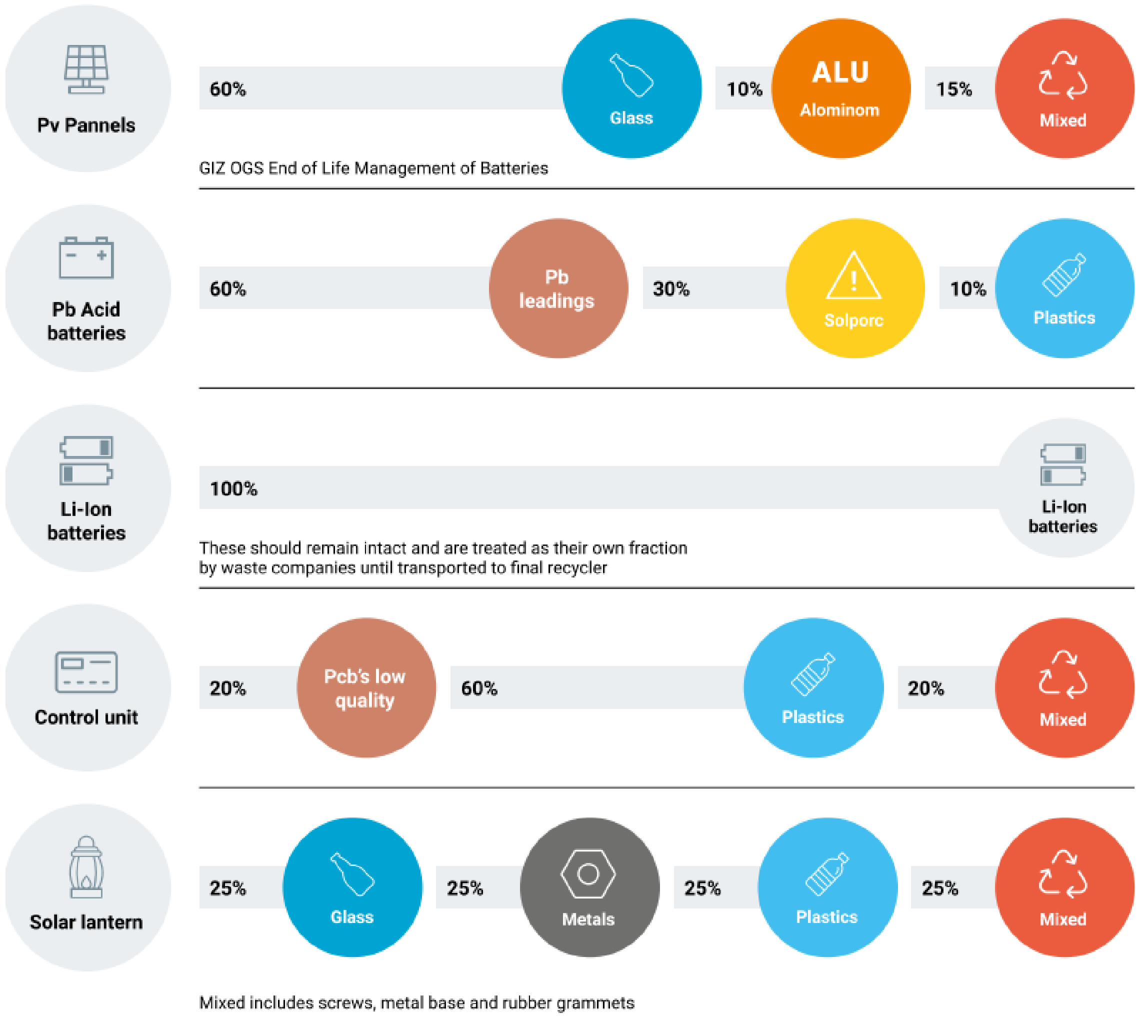

Figure 3: Waste components of an off-grid solar product, image source:(GOGLA, 2019)

2.4.3 Solar PV system waste management: a global regulatory strategy

There are insufficient regulations and laws set by the world's most developed and developing nations regarding the use of PV systems and their functioning without disposal plans.

Photovoltaic waste is classified as hazardous waste (not e-waste) in the majority of countries around the world. For instance, they are recognized as hazardous waste and considered e-waste in the EU, yet none of these terms is used to describe them in the USA. Interestingly, PV panels were excluded from the definition of electronic waste in the original EU WEEE Directive and were only incorporated in the updated version, which was published in 2012 (Magalini et al., 2016).

Some regulatory frameworks have come to address this rise in solar PV e-waste. The UK was the first country to approve the EU WEEE directive, which went into effect on January 1st, 2014. It requires the recording of the number of panels made or imported through distribution networks. Germany has tightened WEEE restrictions for exporters and producers, forcing them to register PV-related products and take responsibility for EoL treatment. The European group WEELABEX provides waste management organizations with guidance while also collecting, storing, processing, and recycling electrical and PV waste.

i. Czech Republic

To recover and recycle used solar panels, a joint venture of PV waste processors was launched in the Czech Republic. It seeks to offer a solution that satisfies all international legal criteria for the processing of solar waste. PV Cycle, a European organization is responsible for WEEE-compliant PV module take-back and recycling. Similarly, both PV Cycle and Retela, a photovoltaic waste processor, have formed a joint venture in the Czech Republic to recover and recycle solar panels. This has encouraged take-back and recycling practices of solar PV waste in the Czech Republic.

ii. USA

California has a program to manage and control the processing of solar PV equipment waste. To limit the dumping of hazardous compounds into landfills, the California Department of Toxic Substances Control supports recycling initiatives. As a result, First Solar, a utility-size project developer collaborated with several companies in the United States and Germany to process feasible solar PV waste. The recycling technique allows for the reuse of about 95% of cadmium and 90% of glass components.

iii. Australia

In Australia, the treatment and disposal of PV systems waste vary by geographical territory. Since 2014, solar waste in Victoria has been classified as e-waste and has been banned from disposal. Although there are several PV panel recycling facilities in Australia, they can only recover and reclaim a tiny percentage of a panel (up to 17% by weight), particularly the aluminium frame and junction box. That indicates that 83% of the remaining waste components from solar PV, such as silicon, polymer back sheets, and glass, have not been recycled. However, a national strategy for PV product management is now being developed.

iv. China

In China, there is no definite EoL obligation on PV wastes and they are not included in the Waste Electrical and Electronic Product Recycling Management Regulation that was passed by State Council in 2009. There is no advanced recycling facility for PV wastes either. This can be accounted for by the low volume of PV waste generated in the present day. However, since China’s PV industry is the largest in the world, they have funded research and development on solar PV recycling techniques. Research institutes such as the National High-tech Research and Development Programme, and Safety Disposal Research are focused on recycling techniques for crystalline silicon PV.

v. India

Currently, India is among the top ten photovoltaic markets in the world. There are no specific guidelines in India for dealing with solar panel waste, and PV waste is handled using waste practices by the government by regulations described in Section 2.1.1. India has already developed an infrastructure for industrial-scale e-waste recycling, but it only applies to household electronics, not PV modules.

2.5 Lessons learned from the global WEEE management and solar e-waste situation

Three main aspects need to be reflected in e-waste management: i) the legislation, ii) the management practices in effect, and iii) the estimation of the e-waste that is being generated.

i. Legislation

Developing countries confront particular difficulties in managing their e-waste because it lacks the infrastructure necessary for proper waste management, e-waste-specific laws, a framework for the reclamation of end-of-life items, and the implementation of extended producer responsibility (Osibanjo & Nnorom, 2007). E-waste legislation and existing regulations governing general waste management are not enforced, as seen in many developing countries. Also, the presence of legislation doesn't directly translate to improvements in WEEE management due to weak enforcement.

ii. Management practices

The majority of developing nations also lack a well-established infrastructure for the separation, storage, collection, transportation, and disposal of e-waste, as well as the ability to effectively enforce laws governing the management of hazardous waste (Yu et al., 2010). Modern recycling facilities and formal recycling of e-waste utilizing effective methods are uncommon. (Kinally et al., 2022)As a result, e-waste is managed using a variety of low-end options, including disposal in open landfills, incinerations and backyard recycling (Bo & Yamamoto, 2010).

iii. Volume of e-waste

As stated before, monitoring e-waste volumes is critical at both the global and national levels to identify strategies for its management. Statistics should be gathered at the global and national levels so that they may be updated, disseminated and analysed regularly.

Measuring e-waste is a critical step toward tackling the e-waste problem. Statistics aid in evaluating changes over time, setting and assessing goals, and identifying optimal policy practices. Improved e-waste data will aid in the reduction of waste generation, the prevention of illegal dumping and emissions, the promotion of recycling, and the creation of jobs in the reuse, refurbishment, and recycling sectors.

3 Waste management in Nepal

In Nepal, there is no particular guideline for the collection and handling of e-waste. E-waste, being a complex waste stream, requires adequate segregation, collection, treatment, and disposal, yet it is currently mixed with municipal waste.

The Solid Waste Management Act of 2068 (2011) and Solid Waste Management Rules 2070 (2013) are prominent pieces of legislation that guide waste management actors in Nepal. They define solid waste as all types of waste, including domestic, industrial, chemical, medical, or hazardous waste, as well as materials and equipment used in electrical and information technology. The regulations cover waste reduction, segregation of solid waste at source (at least organic and inorganic), and correct disposal without providing sufficient guidelines or technical information for treatment and recovery. It also stipulates that the individual or body responsible for creating health institution-related waste, chemical or industrial waste, shall be accountable for processing and managing such waste within the established criteria, however it does not address e-waste.

When it comes to the amounts of various forms of waste, there is no reliable data available to determine their overall generation. In Nepal, all factors required for good e-waste management are lacking. Therefore, interviews with institutes were done to have a better understanding of the future steps.

To get a clearer picture of the current situation of the e-waste management scenario in Nepal, POSTED conducted interviews with private companies and non-governmental organizations (NGOs).

The main objective of the interviews was to understand the mechanism of waste management as a whole unit instead of just focusing on EEE. Since Nepal lacks a proper waste management system and policies, it was essential for this study to understand the current management strategies of private companies and NGOs working in the waste management sector.

First, a list of private waste management companies and NGOs (working in waste management) was prepared. Eleven private waste management companies were identified along with two NGOs. A questionnaire was developed and they were approached for interviews. Out of the eleven-waste management companies, seven private companies and one NGO agreed to an interview. All companies were located in Kathmandu. Out of the seven private companies interviewed, one company had not started operations and was in the initial pilot phase, hence, excluded from the analysis.

After the interview, an overview was developed of the waste management practice in Nepal which is illustrated in. In Nepal, the waste management system is not straightforward. Its operation is greatly interconnected with the informal sector. As shown in Figure 4, even though waste management companies collect waste directly from users, the informal sectors end up with the majority of the waste. There are exchanges between the companies and informal sectors as well.

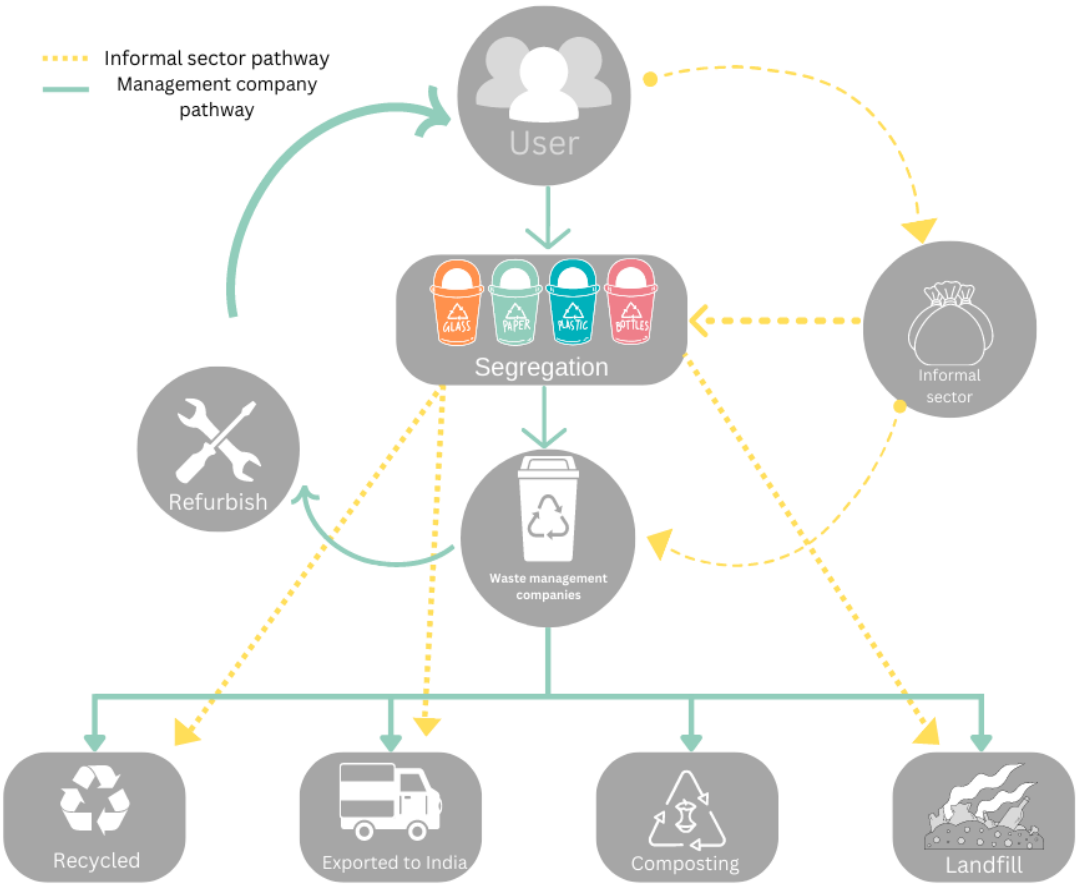

Figure 4: Waste management system in Nepal

3.1 Collection of waste

The majority of companies have a collecting mechanism in place. While Nepal Pollution Control and Environment Management Centre (NEPCEMAC) has contracts with individual wards for a set period, other companies, such as Doko recyclers, have their trucks for a specific region and go out to user groups who contact them to collect waste. Some companies like Thulo Kawadi and Avni Ventures collect waste also from the informal sectors which emphasizes the involvement of informal sectors. Table 4 gives an overview of the collection mechanism of waste management companies and an NGO interviewed.

Table 4: Waste collection systems of waste management companies/NGOs

Companies	District	Waste collection system
Doko Recyclers	Bhaktapur	Pick-up service, fixed drop-off locations
Thulo Kawadi	Kathmandu	Pick-up service, from informal sectors
Avni Ventures	Kathmandu	Pick-up service, from informal sectors
Blue waste to Value	Kathmandu	Pick-up service, hotels, wards
Upcycle	Kathmandu	Drop off location
NEPCEMAC	Lalitpur	Collection from specific ward
Creasion (NGO)	Kathmandu	From transfer station and informal sectors

3.2 Waste sorting and dismantling

The most rigorous part of waste management in Nepal is waste sorting once it has been collected. This is because the majority of the waste collected is not segregated at the source, thus, this stage demands the greatest time and labour. Table 5 gives a summary of the waste segregation and dismantling activities of interviewed companies. While companies such as Doko and NEPCEMAC require customers to segregate waste at source, they do have a segregation facility to sort, dismantle and store dry waste (i.e., metals, plastic, paper, etc.). Additionally, Thulo Kawadi and Avni are two companies that gather the sorted waste from the informal sectors and send the waste for recycling.

While NGOs like Creasion assist in waste segregation through volunteer efforts, they sort waste in transfer stations, mostly plastic and organic waste.

Table 5: Waste management mechanism of private companies/NGOs

Companies	Waste segregation and dismantling
Doko Recyclers	Sorting and dismantling facilities
Thulo Kawadi	Sorting and dismantling facilities
Avni Ventures	Only storage of sorted wastes
Blue waste to Value	Sorting and dismantling facilities
Upcycle	Only storage of textile
NEPCEMAC	Sorting and dismantling facilities
Creasion (NGO)	Sorting in a transfer station

3.3 Recycling

None of the companies completely recycle waste materials. However, companies do refurbish or reuse a certain portion of waste when feasible, for example, refurbishment of washing machines, hair dryers etc. and reuse of glass bottles. Otherwise, the majority of the sorted waste is either transported to recycling centres of plastic, metal or glass; or exported to India. Furthermore, a significant proportion of dry sorted waste, such as paper, plastics, and metals is also sent to companies as raw materials. For organic waste management, all of the firms advocate composting.

The remainder of the waste that cannot be recycled, reconditioned, or composted ends up in a landfill. Similarly, waste not collected by companies and managed within the informal sector also ends up in landfills or is incinerated.

3.4 E-waste management in Nepal

Since Nepal lacks e-waste management regulations and guidelines. As a result, suitable infrastructure for appropriate WEEE management is missing in Nepal. Nepal needs to establish and enforce e-waste regulations, create a framework for the reclamation of end-of-life items and establish a proper monitoring system to estimate the amount of e-waste being produced.

The current situation of e-waste management in Nepal is in a rudimentary state. Even though 4 out of the 7 companies claimed to have managed e-waste, the management mostly extended to sorting, dismantling, and separating various parts, and selling the recyclables. Materials for which companies lack the knowledge and technology to recycle were sent to landfills. Table 6 lists the companies involved in e-waste management.

Table 6: Table listing the companies interviewed

Name of the company	Area of focus	Involved in EEE management
Doko Recyclers	Solid waste management	Yes
Thulo Kawadi	Solid waste management	Yes
Avni Ventures	Multilayer plastics & polyethene terephthalate (PET) bottles	Yes
Blue waste to Value	Solid waste management	Yes
Upcycle	Textile	No
NEPCEMAC	Solid waste management	No
Creasion (NGO)	Plastic and PET bottles	No
Fohor Malai	*(Pilot stage, have not started operations, therefore, excluded from analysis)*	-

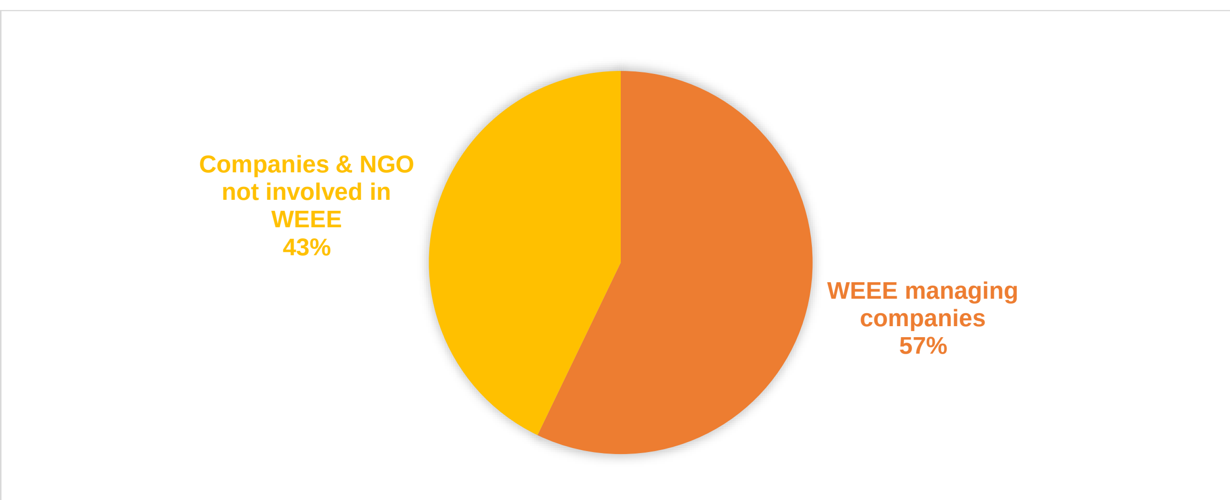

Figure 5: Pie chart showing the percentage of waste management organizations (out of 7) involved in e-waste

3.5 Limitations, challenges and insights from companies

Following talks with waste management companies and non-governmental organization, no adequate waste-collecting mechanism exists in Nepal. The prevalence of the informal sector appears to be the biggest hindrance to formal waste management because the informal sector is mostly in charge of collecting and processing waste. Even private waste collection and processing companies lack regulations and norms to formalize their waste management operations. Plastics, paper, metals, and textiles are the most common recyclables collected by companies and informal sectors that are sold to a few recycling companies or exported to India. If feasible, EEE is refurbished; otherwise, due to a lack of treatment facilities, e-waste, after it is dismantled and recyclable plastics and metals are extracted, is landfilled alongside other municipal waste.

One of the main limitations mentioned by the waste management companies was the lack of e-waste-specific policies, awareness and implementation of existing regulations for solid waste management. Some major limitations and challenges mentioned are listed below.

- There are no effective mechanisms or policies in place to collect waste, including e-waste, from households and other consumer entities.
- There is a lack of data on the number of people involved in importing, assembling, or selling EEE, as well as the exact quantity of EEE in the market.
- Illegal and undocumented imports of various forms of EEE and its components will always present a risk to effective e-waste management.
- There is a lack of awareness, incorrect segregation, lack of household waste data, and the temporary/permanent storage of waste within a household. These shortcomings must be addressed to improve management processes.
- Use of manual techniques for waste dismantling, processing and disposal which are inefficient and expensive.

To improve current practices, the first step should be to create and enforce a national e-waste policy that addresses the limitations and challenges described above. One of the biggest issues, as emphasized by the companies, appears to stem from a lack of trustworthy and publicly available data and statistics on the quantity of waste in Nepal. As a solution, companies prioritized technology, data, policy, awareness and recycling as five major areas of focus for e-waste management in Nepal (as shown in Figure 6).

Figure 6: Solutions proposed by the waste management companies and NGOs

The foundation for developing the facilities and infrastructures for the collection, transportation, and treatment of e-waste is first quantifying the amount of e-waste generation. Thus, it is required to study the material flow and develop a suitable model to quantify the amount of e-waste generated and forecast e-waste that will be generated in the future.

3.6 Status of solar e-waste in Nepal

Nepal has no specific guidelines for solar PV-specific e-waste disposal which is not strange considering the country's lack of adequate legislation and proper implementation on both solid waste and e-waste. Doko recyclers claim to have collected solar home systems, however, owing to a lack of recycling knowledge on the technology, the majority of the components end up in landfills. In the battery sector, three companies, namely, Doko recyclers, Avni ventures and Thulo Kawadi, claim to have collected batteries. However, out of the three, only Doko recyclers neutralize the batteries, whereas, the rest resell them to the informal market. Although there appears to be some awareness of e-waste, companies are completely uninformed of the potential future waste generated by the solar PV sector due to a lack of data and analysis.

4 Projection of solar PV e-waste in Nepal

A dearth of proper quantification of solar e-waste was observed during this study. Appropriate categorization of products entering the market is crucial for any successful e-waste management project as it will help inform the appropriate technology for its treatment. Furthermore, comprehensive quantification and monitoring of e-waste would assist policymakers in understanding the scope of the problem and developing a timely sustainable management strategy.

Since there is no actual data or monitoring of solar PV waste in Nepal, information was extracted from the annual customs statistics (import data) as well as from the Alternative Energy Promotion Center (AEPC) annual progress reports, which are presented in the following sections. Even though both customs data and the deployment data are incomplete and difficult to systematically filter due to changing reporting format from year-to-year, an experimental approach for estimating the solar PV e-waste generated can be developed.

4.1 Customs data on solar PV components

Customs data were analysed to obtain the number of solar PV systems imported into Nepal. However, the data collected does not reveal the entire scope of the solar PV systems imported. The overall extracted data is presented in Annexe I.

Table 7 summarizes the publicly accessible import customs data. The obvious anomaly is the inconsistent Harmonized System (HS) codes[1] and the titles under which various solar PV components are classified. This is one of the main reasons why extracting appropriate data from the existing data set is challenging.

First off, solar PV cells are classified as "photosensitive semiconductor devices," with a notation emphasizing that this category encompasses all semiconductors, including PV cells. Since it comprises other semiconductors, this data set may not accurately depict solar panels imported. Furthermore, solar PV cells were only recently classified as a distinct unit since 2021.

Table 7: Snippet of available import customs data on solar PV systems (Source: Department of Customs Nepal)

Components	HS code	Fiscal Year	Units
Solar PV cells			
Photo-sensitive semiconductor device	85414000	2018	961,597
Photo-sensitive semiconductor device	85414000	2019	260,133
Solar PV modules	85414910	2021	62,455
Solar PV Modules	85414910	2022	6,759
Batteries			
Battery parts	85069000	2009	9,104,921
Lead-acid accumulators	85071000	2012	477,101

[1] The Harmonized System is a standardized numerical method of classifying traded products. It is used by customs authorities around the world to identify products when assessing duties and taxes and for gathering statistics.

Lead-acid accumulators	85072000	2013	489,028
Tubular Battery for Solar	85072000	2015	79,036
Solar charge controller			
Solar equipment	85412900	2015	15,780
Solar charge controller	85044000	2016	3,271,634

Second, the batteries have been classified as "Lead-acid accumulators," which includes all lead-acid batteries except piston engine batteries. Other batteries, such as those used in electric vehicles are also included in this category, which results in huge numbers being recorded in this category. Thus, this data does not accurately quantify batteries imported for solar PV applications. In addition, there are discrepancies in the name and arrangement of the solar batteries-related data. For example, according to the data presented in Annexe I, solar batteries have been categorized as "Tubular batteries for solar" only three times (in 2015, 2016 and 2017).

Furthermore, the solar charge controller has the least amount of data sets, with inconsistent HS code and category names. Therefore, there is a lack of proper characterization and distinction in customs data and improvements in data handling is required for correct data extraction.

4.2 Solar PV system deployment data

AEPC is Nepal's principal agency responsible for promoting renewable energy. They manage and document the deployment of renewable energy technologies. Their website has some statistics on solar PV systems installed and the annual reports since 2009 are available online. Table 8 shows AEPC's cumulative deployment of various solar PV systems in Nepal until 2021. The overall yearly deployment data extracted from the annual reports are presented in Annexe II.

Table 8: Cumulative solar PV systems installed in Nepal till 2021

Solar PV technologies	Units installed
Solar home systems	974,001 nos.
Institutional solar PV system	3,817 nos.
Urban solar home systems	21,144 nos.
Solar drinking water and irrigation pump	3,129 nos.
Solar mini-grid	2,929 kW

4.3 Solar e-waste monitoring mechanism

In this section, an experimental method for solar PV e-waste monitoring mechanism is developed using AEPC's data on the system deployed. The e-waste projection made in this section is closely linked to the sales obsolescence method as described in Section 2.3.

The projections are made for five technologies as follows:

i) Solar home systems
ii) Institutional solar PV systems
iii) Urban solar home system
iv) Solar drinking water and irrigation pumps
v) Solar mini-grids

For each technology, the number of systems deployed was obtained from AEPC's past progress reports and statistics reported on the AEPC website. The technologies were divided into major components. For example, the major components of an institutional solar PV system are panels, battery inverter and batteries. Similarly, for each technology, a typical size of the system (and its components) is assumed which will allow for component-wise e-waste projection. The typical size of the system is described in the table below.

PV technology	Typical system size assumed
Solar home system	100Wp panel, 100W battery inverter, 480Wh lead-acid battery bank
Institutional solar PV systems	1,950Wp solar PV array, 1,500W battery inverter, 9,600Wh lead-acid battery bank
Urban solar home system	975Wp solar PV array, 700W battery inverter, 4,800Wh lead-acid battery bank
Solar drinking water and irrigation pump	1,300Wp solar PV array, 1,000W solar pump inverter
Solar mini-grid	60,125Wp solar PV array, 4,600W battery inverter, 25,000W grid-tied inverter, 288,000Wh VRLA Gel battery bank

Now, for each component within the system, the end-of-life years are estimated based on the operational life of each component as shown in Table 9. For the projections of e-waste, the lower-end values of the range of operational life are taken.

Table 9: Typical operational life of major solar PV system components

Component	Range of operational life	Value taken for end-of-life projection
Solar PV modules	25 –30 years[2]	25 years
Batteries – lead acid	5 – 7 years[3]	5 years
Inverters (battery inverter, grid-tied inverter and solar pump inverter)	10 – 15 years[4]	10 years

[2] Energy.gov, "What Is End-of-Life Management for Photovoltaics?," Energy.gov, March 2022. [Online]. Available: https://www.energy.gov/eere/solar/end-life-management-solar-photovoltaics#:~:text=The%20estimated%20operational%20lifespan%20of,in%20the%20next%20few%20decades.. [Accessed 4 November 2022].
[3] K. Turcheniuk, D. Bondarev, V. Singhal and G. Yushin, "Ten years left to redesign lithium-ion batteries," Springer Nature Limited, vol. 559, pp. 467-470, 2018.
[4] R. Kennedy, "How long do residential solar inverters last?," PV Magazine, 16 September 2021. [Online]. Available: https://www.pv-magazine.com/2021/09/16/how-long-do-residential-solar-inverters-last/. [Accessed 10 November 2022].

Similarly, the breakdown of the major components for each solar PV technology and its end-of-life is illustrated in Figure 7.

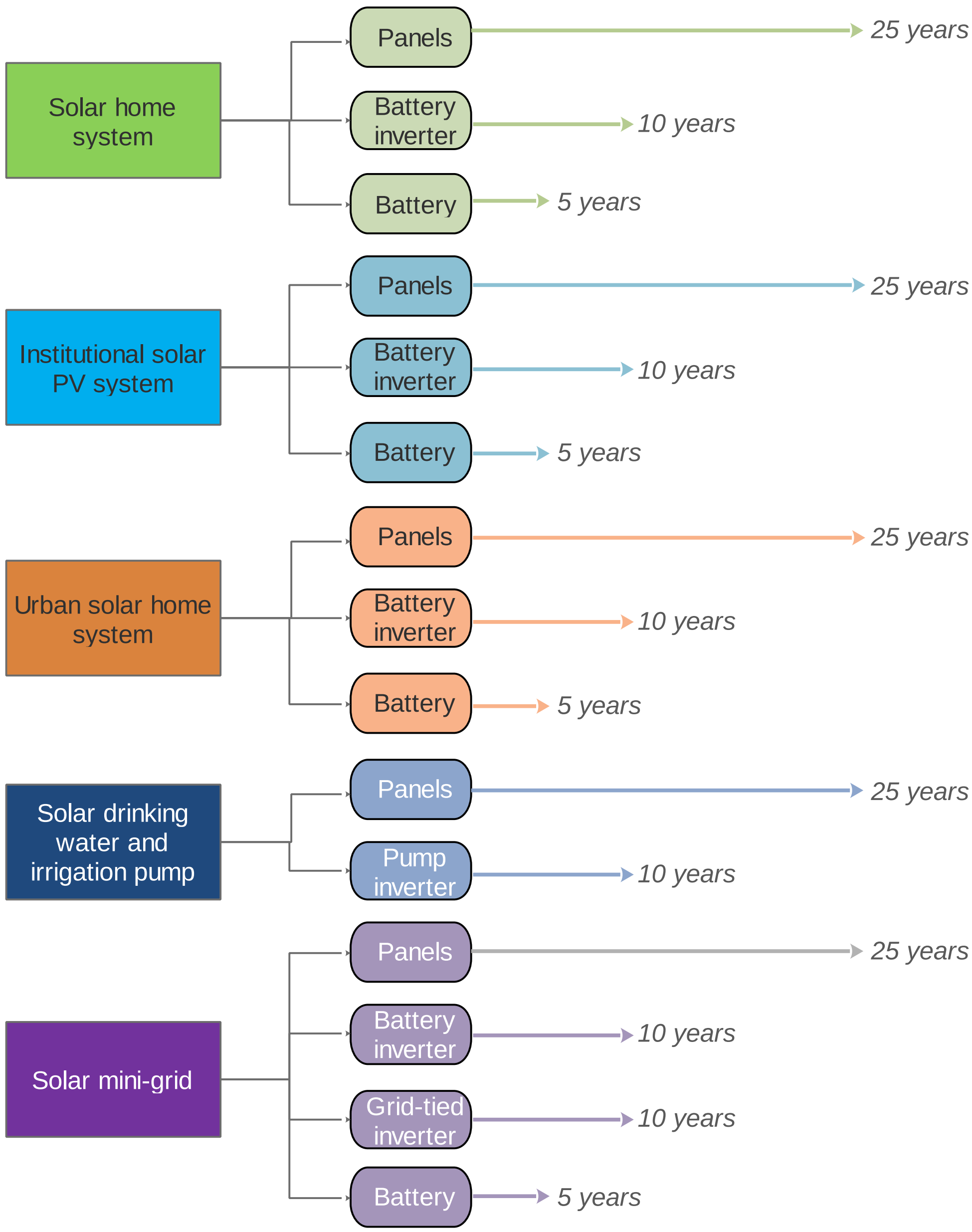

Figure 7: Major components for each solar PV technology and its end-of-life year

For a detailed breakdown of system components, see Table 12 in Annexe III.

AEPC has reported the number of systems deployed for each technology in its progress report except for solar mini-grids, which are reported in terms of cumulative kW deployed. Now, the volume of components installed (panels, battery etc.) is estimated based on the total systems installed. For example, if one solar water pumping system is installed, it is assumed that 4 solar panels of 325Wp each (1,300Wp array) and a 1kW solar pump inverter are installed.

After the total number of components installed is estimated, the number of components is converted into the total weight of components. For example, 4 solar panels of 325Wp weigh 88kgs (on average 22kg per panel).

Now, each component is considered waste after its end-of-life period. For example, solar panels installed in the year 2018 become waste in the year 2042. In this manner, the volume of e-waste is estimated for each major component of solar PV systems.

The uncertainties of this analysis are the following:

i) There are gaps in the annual data on the system deployed which results in uncertainty in the calculated volume of e-waste.
ii) A typical system capacity is assumed for each solar PV technology due to a lack of data on individual system capacity.
iii) A single battery technology i.e., lead-acid has been taken for the projection. However, battery technologies have evolved having longer cycles such as VRLA OPzV batteries, lithium-ion batteries etc.
iv) A single data source based on systems deployed by AEPC is taken. The data does not include systems developed and deployed by the private sector, development partners and other institutions that did not receive AEPC subsidies.
v) To get an accurate prediction of solar PV e-waste, data gaps, inconsistencies and outliers were reduced using approaches such as averages and moving averages.

The projections are made to describe the methodology of solar PV e-waste projection, observation of the trend and estimate the range of metric tons (MT) of waste produced.

4.3.1 Solar panels waste projection

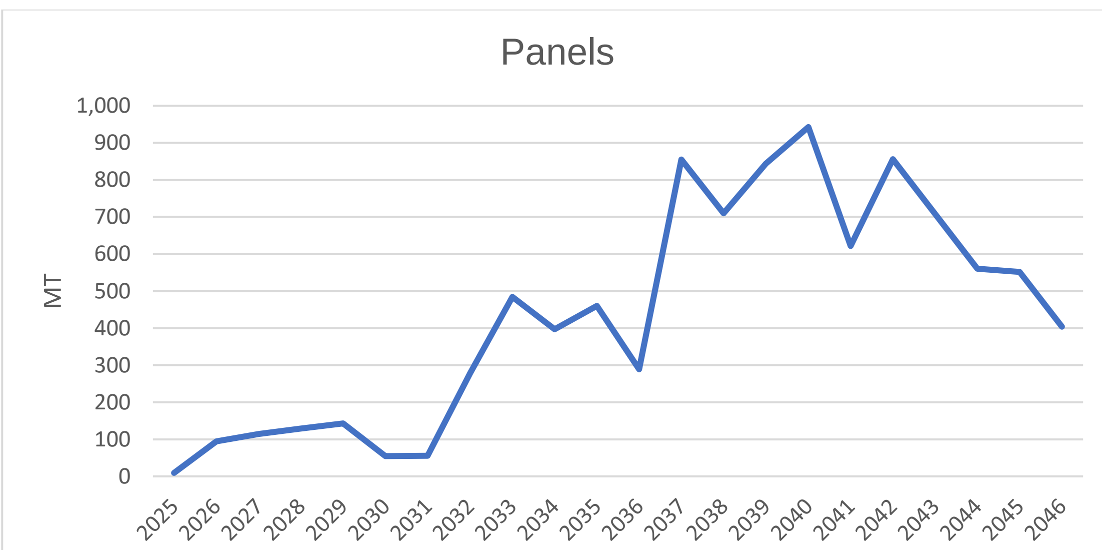

Figure 8: Solar panels waste projection

The figure above shows that the total quantity of waste from solar panels is expected to rise over time. According to the rising and then declining record of the number of solar home systems deployed over the years, there is a growing trend with a dip towards later periods.

However, there were some data discrepancies, such as the total number of solar panels installed in all urban solar home systems reported in 2018, as well as data gaps between 2004 and 2020 where no data were recorded. To provide a clear prediction for e-waste generation, the reported cumulative data given was split into three years (i.e., according to the timeframe the scheme was active for), and data gaps in 2004 and 2020 were estimated by averaging the number of systems in the preceding and subsequent years.

The volume of solar panel waste is estimated to reach 855 MT by the year 2037. The Government of Nepal continues to support solar PV technologies, such as solar mini-grids to close the gap on last mile electrification and solar water pumps for drinking water and irrigation. Furthermore, as confidence in solar PV technology grows, the private sector is developing solar grid-tied systems for commercial and industrial users as well as utility-scale solar PV plants. After the recent completion of a 25MW utility-scale solar PV plant developed by the Nepal Electricity Authority (NEA), further development of the cumulative 100MW capacity of utility-scale solar PV plants are underway. Given these recent developments, the volume of solar panels deployed in Nepal will continue to increase.

The year-to-year decrease and increase in solar panel waste are due to the following factors:

i) Data gaps on the number of systems deployed for any particular solar PV technology.
ii) The growth and even phasing out of AEPC's subsidy for any particular solar PV technology. For example, AEPC is increasingly supporting solar mini-grids in recent years while it is decreasing support in solar home systems.

See Table 13 of Annexe IV for details.

4.3.2 Battery waste projection

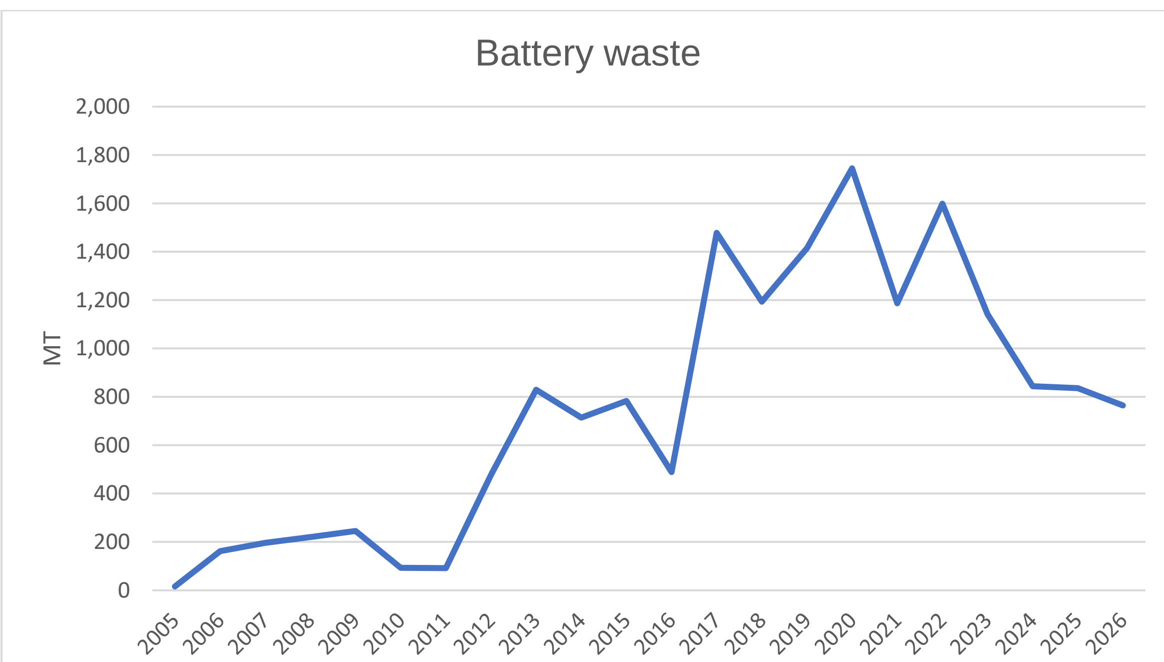

Figure 9: Batteries waste projection

According to the figure above, the total amount of battery waste is increasing. When compared to other components of the solar PV system, battery waste has the highest volume, with a maximum volume of 1748 MT. This can be attributed to the short EoL of batteries. Similar to the forecast for panel waste, there is a considerable increase and gradual drop in battery waste production over time. This is due the deployment trend of solar PV systems over the years. Likewise, the battery waste projection has inconsistency (i.e., 2022 due to cumulative reporting of urban solar home systems in the year 2018) and data gaps in 2004 and 2020. Data discrepancy has been addressed in the same way as solar panel data.

The volume of battery waste is estimated to have reached 1,478 MT in 2017. As the deployment of solar mini-grids and other solar PV technologies for off-grid areas continues to progress, the volume of batteries deployed will increase. Furthermore, as solar PV with energy storage projects is developed to address the limitations of variable renewable energy generation, the deployment of batteries will become more profound. Furthermore, due to advancements in battery technologies and a wider range of applications, such as the increasing popularity of lithium-ion batteries, will see a diverse deployment of batteries in solar PV systems.

The year-to-year decrease and increase of battery waste are also due to the same factors described for solar panel waste projection, i.e., data gaps and trends of AEPC's support for any particular technology.

See Table 13 of Annexe IV for details.

4.3.3 Battery inverter waste projection

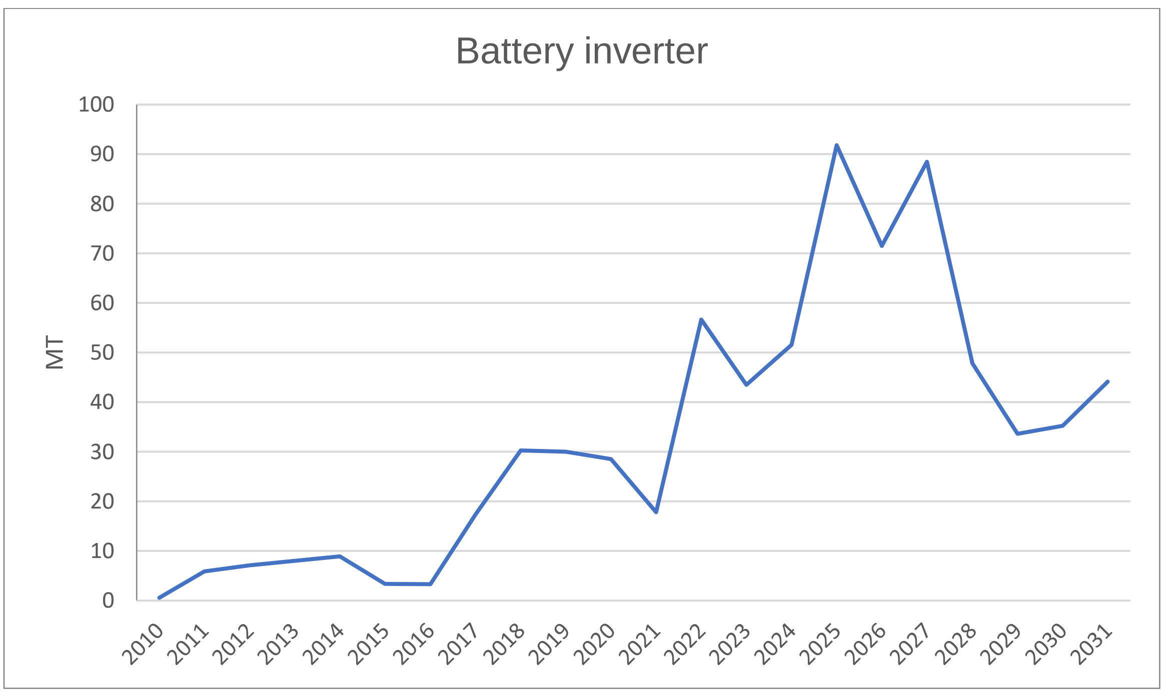

Figure 10: Battery inverters waste projection

According to the graph above, the overall quantity of waste generated by battery inverters is gradually increasing. The general trend of the battery inverter is similar to that of solar panels and batteries; a significant increase and a gradual fall corresponding to the solar home system deployment trend.

The data gaps (i.e., between 2004 and 2020) and cumulative reporting were resolved using the same approaches as in the case panels and batteries.

The volume of battery inverters is estimated to have reached 57MT in 2022 which is magnitudes less than the volume of solar panel and battery waste. As solar PV with energy storage systems (either off-grid or grid-tied) increases, the deployment of battery inverters will continue to rise.

The year-to-year decrease and increase of battery inverter waste are also due to the same factors described for solar panel waste projection, i.e. data gaps and trends of AEPC's support for any particular technology.

See Table 13 of Annexe IV for details.

4.3.4 Solar pump inverter waste projection

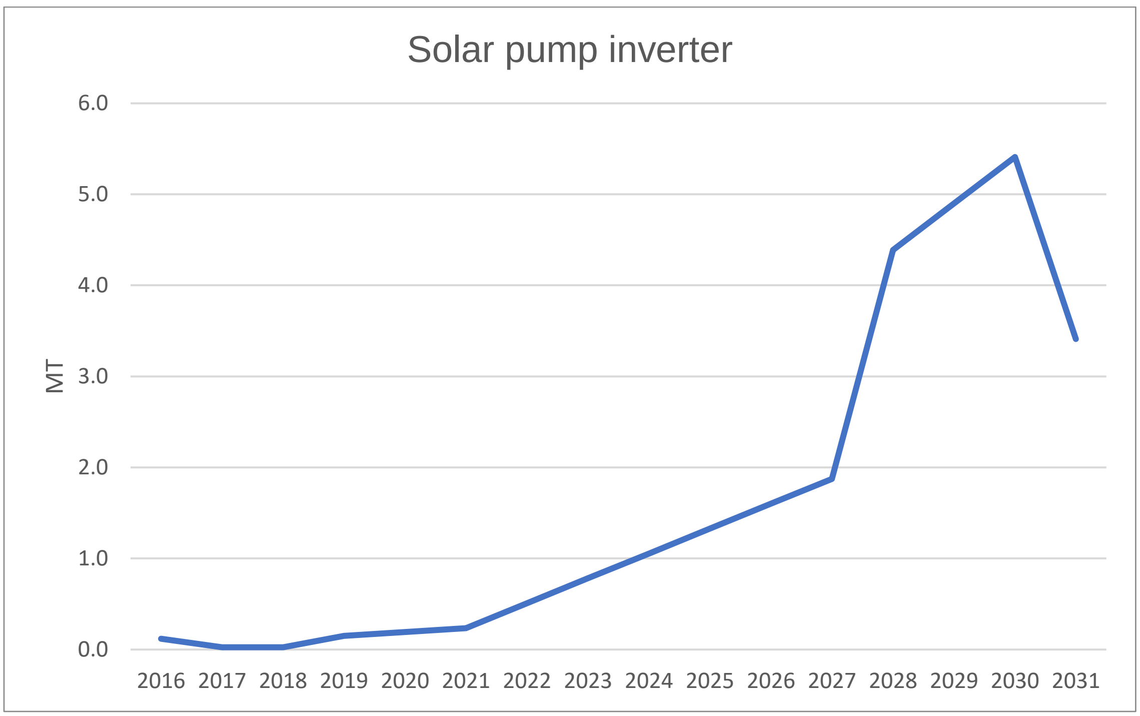

Figure 11: Solar pump inverters waste projection

The figure above depicts the overall progressive increase in the volume of waste generated by solar pump inverters. The solar pump inverter waste projection forecast has a slow but constant growth with a declining trajectory in later years. Data discrepancies in the form of data gaps are prevalent in the case of solar pump inverters, owing to a lack of consistent data reporting of solar pump inverters.

The data gaps can be observed in 2011, and 2020 have been remedied by averaging the values from the preceding and succeeding years. Following that, the major data gap between 2013 and 2017 was addressed using the moving average approach to close the forecast gap for the years 2021 to 2027.

The volume of battery waste is estimated to reach 5.4MT in 2030 which is magnitudes less than the volume of solar panel and battery waste. The Government of Nepal continues to support solar water pumping systems with subsidy schemes and with few organisations exploring grid-connected solar water pumping systems, deployment of solar pump inverters will continue to increase.

See Table 13 of Annexe IV for details.

4.3.5 Grid-tied inverter waste projection

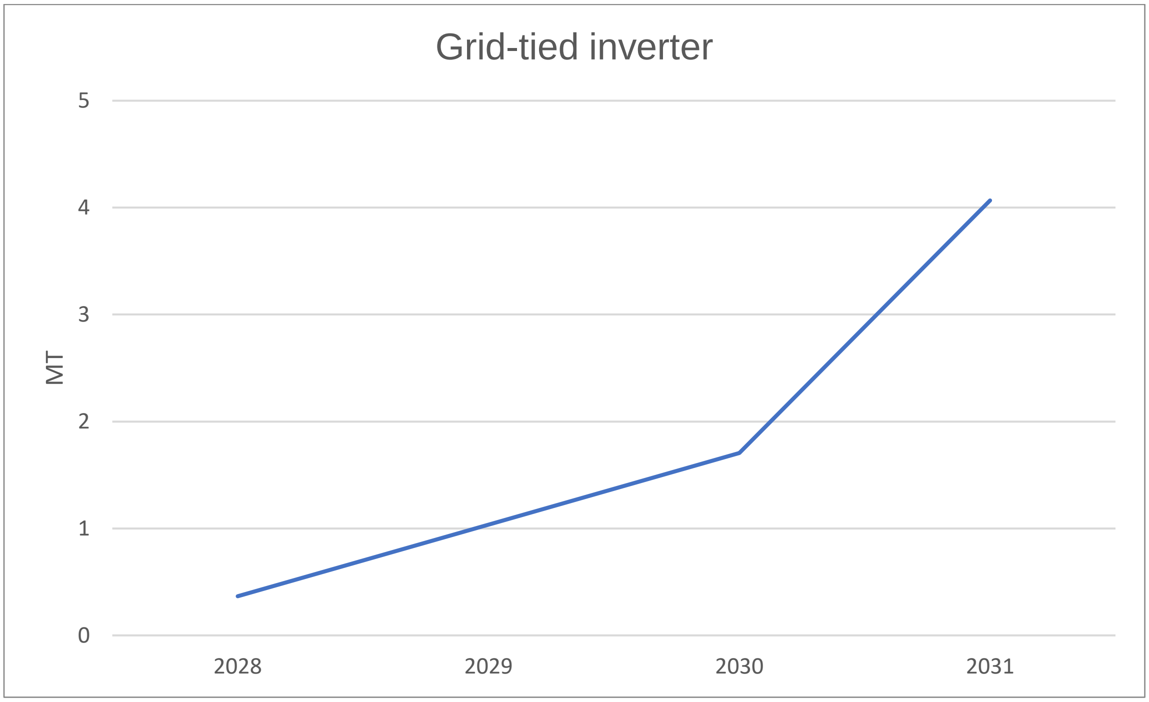

Figure 12: Grid-tied inverters waste projection

From the figure above, although the data points are less and based on the grid-tied inverters estimated for AC-coupled solar mini-grid systems, the grid-tied inverter waste volume in the future is in an increasing trend. There is a data gap in 2020 that corresponds to the zero-waste reported in 2029, which is addressed by averaging the prior and following years for reliable forecast of waste generation.

The volume of grid-tied inverter waste is estimated to reach 4.1MT by 2031 which is magnitudes less than the volume of solar panel and battery waste. It is important to note that these grid-tied inverters are estimated for AC-coupled solar mini-grids and not household, commercial and industrial grid-tied systems, and utility-scale solar PV plants due to a lack of nationally representative data.

See Table 13 of Annexe IV for details.

4.3.6 Comparative solar PV components waste volumes

Figure 13 shows the amount of e-waste projected for all major solar PV components. The projections show that a greater emphasis should be given to managing e-waste from solar panels and batteries compared to other components. Furthermore, managing battery waste (lead-acid) is a priority given its lower EoL years compared to other components.

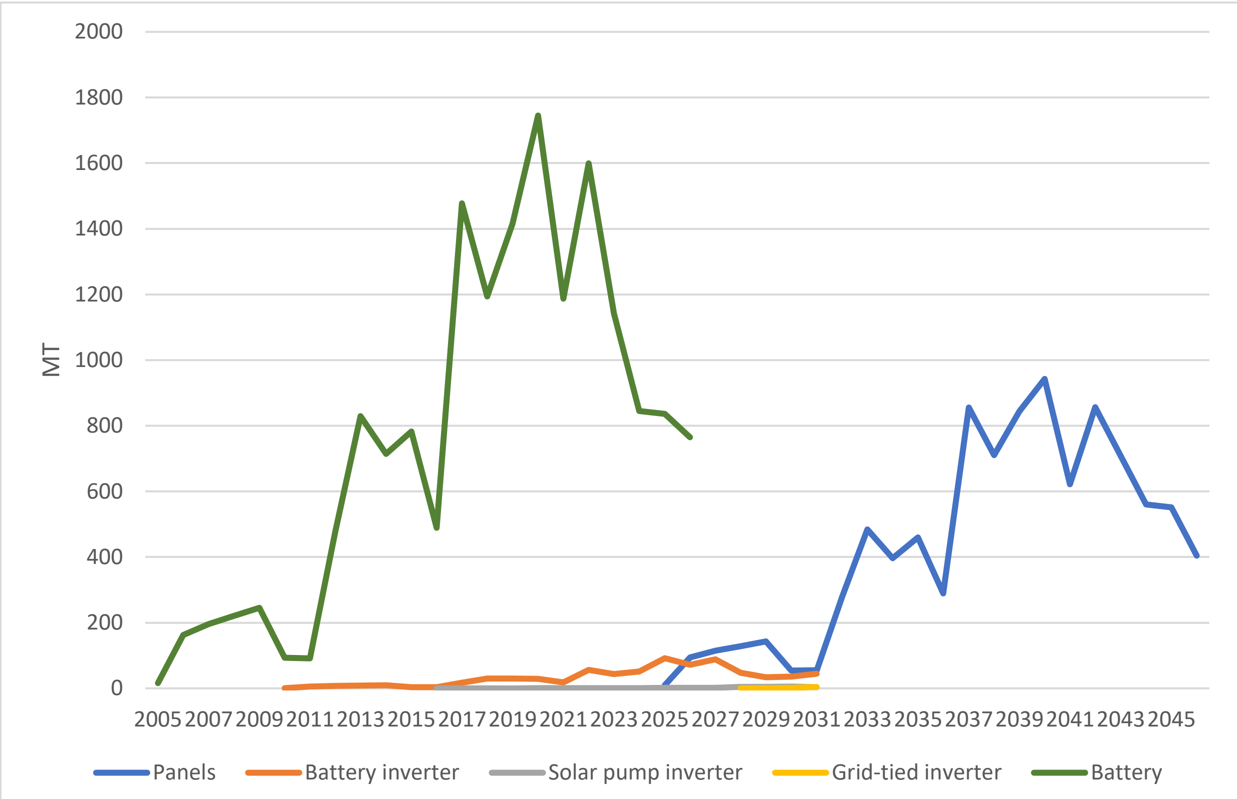

Figure 13: Projected waste volumes of major solar PV components

4.3.7 Solar PV e-waste projection

The projections described in the earlier section aim to establish the methodology for the quantification of e-waste of major solar PV components. However, the results do not claim to represent a complete national scenario of solar PV e-waste projections. The methodology and future projections do, however, expose gaps that need to be filled for an accurate national solar PV e-waste projection. The factors that would strengthen the analysis are the following:

- Reliable and consistent *central* record of solar PV systems deployed with details of the numbers deployed and their capacities (kW, kWp etc.). This should not only include systems supported by government entities (such as AEPC) but should aim to encapsulate all solar PV systems installed in Nepal.
- Consistent and proper categorization of solar PV components in the import data of the customs department.

Improving on the methodology of the previous section, the following flowchart illustrates a possible path to solar PV e-waste monitoring.

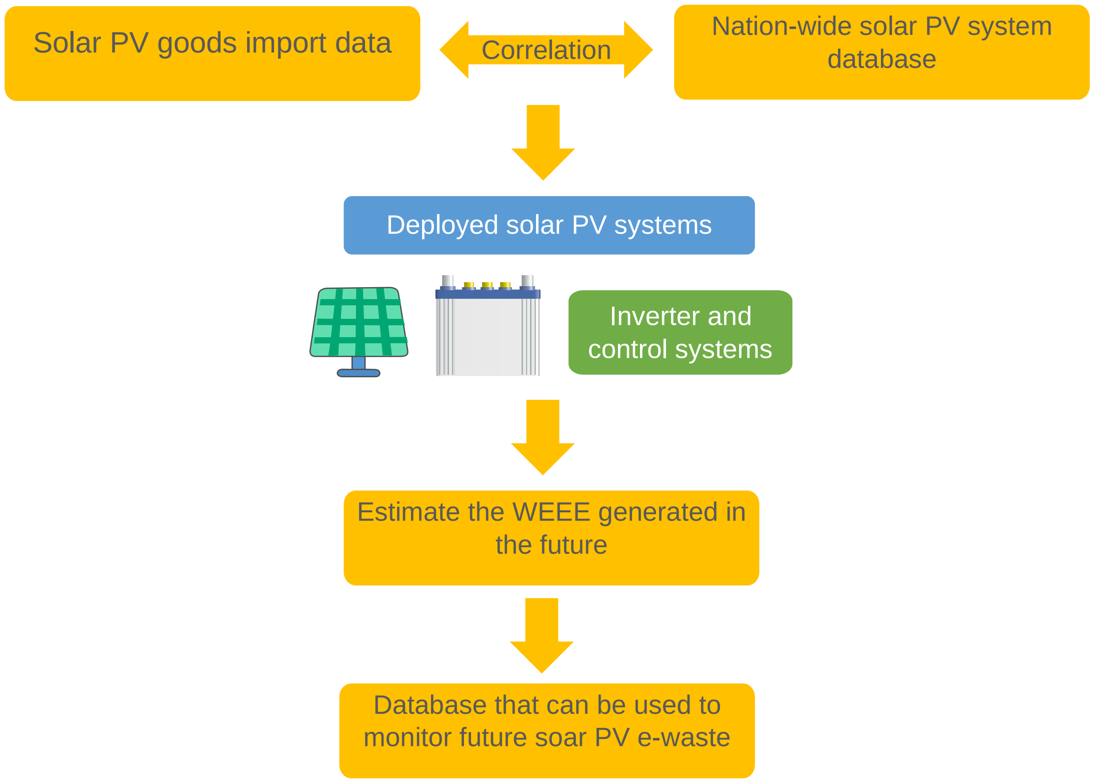

Figure 14: Methodology for solar e-waste monitoring

To further provide accuracy to solar PV e-waste monitoring, coupling import data with AEPC's database on systems deployed, projections can be made on the magnitude of solar PV e-waste respective to provinces and local levels as depicted in Figure 15. With province-level and local-level solar PV e-waste projections a national solar PV e-waste plan can be effectively implemented in coordination with local levels.

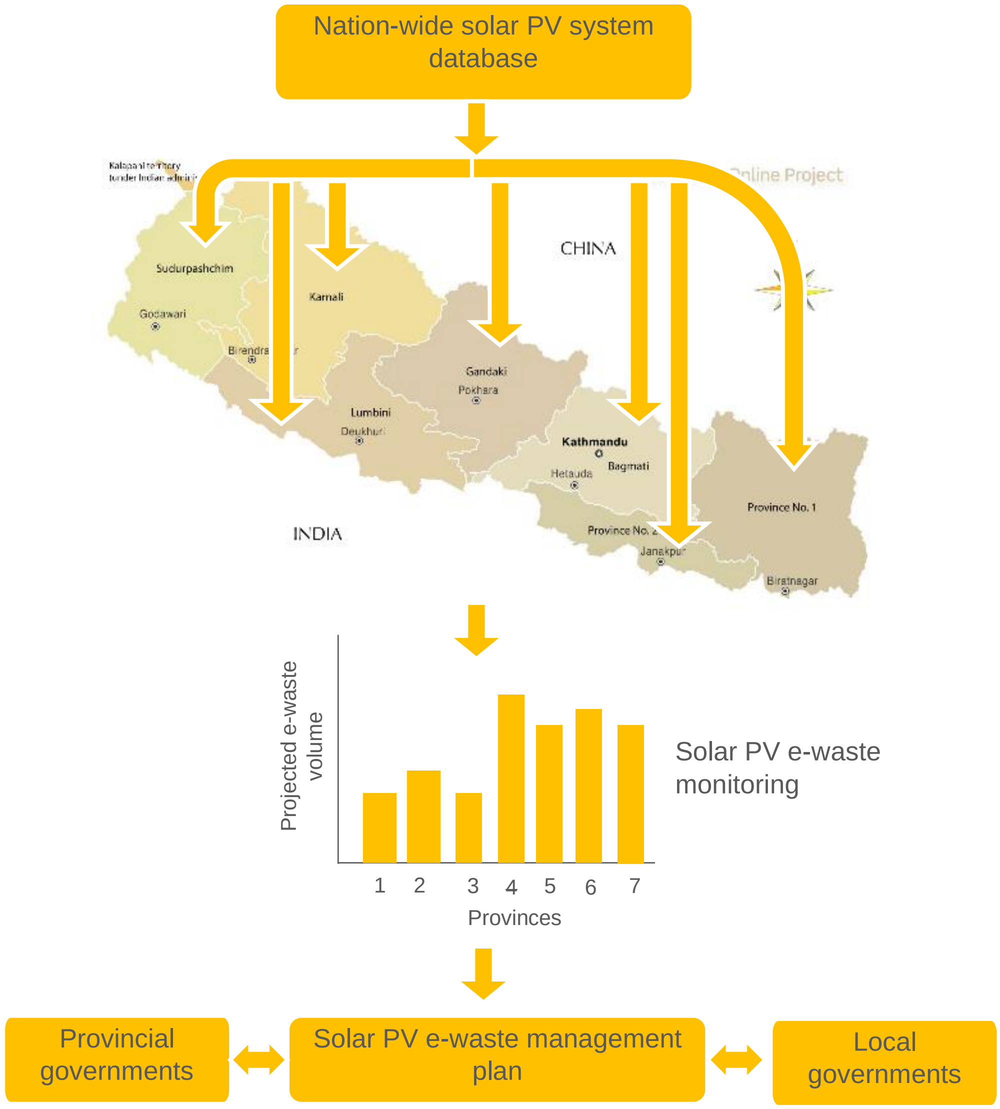

Figure 15: Province-wise or sub-region-wise solar PV e-waste monitoring method

5 Conclusion

E-waste management is a growing and major concern for many governments throughout the world. It includes toxic elements that, if not properly controlled, have harmful effects on the environment and human health. To control e-waste, developed countries have enacted strict regulations. However, in developing nations such as Nepal, there is a lack of regulations on e-waste management (with none for solar PV systems) as well as enforcement of policies.

A framework for managing and treating e-waste should be established by government authorities in emerging and transitioning nations such as Nepal. Increasing information campaigns, awareness, and capacity building is also an important part of proper e-waste management as evidenced by the companies interviewed in this study. Significant attention needs to be given to information management systems for identifying what contributes to e-waste generation as Nepal lacks data, definitions, and even confusion about the responsible ministry for solar PV e-waste management. A formal definition of what solar PV e-waste means for Nepal is yet to be defined.

From the interviews conducted during this study, although there appears to be some awareness of e-waste, waste management businesses are uninformed of the potential future waste generated by the solar PV sector due to a lack of data.

Using AEPC's historical records of solar PV systems deployed, estimation of the volume of major solar PV components i.e. solar panels, batteries, battery inverters, solar pump inverters and grid-tied inverters is done based on the sales obsolescence method. The results show that all major components follow an increasing trend of e-waste with solar panels and batteries having the highest e-waste volumes. Solar panel e-waste is projected to reach 846 MT in 2037 while, based on historical records, batteries (lead-acid) reached 1,478 MT in 2017. Similarly, battery inverters, solar pump inverters and grid-tied inverters are projected to reach 57 MT in 2022, 5.4 MT in 2030 and 4.1 MT in 2031 respectively. E-waste of solar PV components will rise as the deployment of solar PV systems in Nepal continues to increase.

The experimental projections have exposed that the availability of reliable data hinders accurate modelling of nationally representative solar PV e-waste monitoring and projection. To strengthen solar PV e-waste monitoring, the following aspects must be given priority:

- Reliable and consistent *central* record of solar PV systems with details of the numbers deployed and system capacities (kW, kWp etc.). This should not only include systems supported by government entities (such as AEPC) but should aim to encapsulate all solar PV systems installed in Nepal.
- Consistent and proper categorization of solar PV components in the import data of the customs department.

Upon access to reliable data, the import data from customs can be correlated with data on the number of solar PV systems deployed in Nepal. Then using the sales obsolescence method, an accurate e-waste monitoring model can be developed based on end-of-life years for each major solar PV component. A centralized e-waste monitoring mechanism is likely to encourage more players in the market to explore business models for solar PV e-waste management. Since one of the points raised by companies during the interviews was the lack of public data on solar PV e-waste leaving it under the radar of waste management.

This report, with its recommendations on the methodology of solar PV e-waste monitoring, aims to become an entry point for further e-waste monitoring research and activities.

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7 Annexes

7.1 Annexe I

Table 10: Imported solar PV systems from 2007-2022 (source: Department of Customs Nepal)

Components	HS codes	Financial Year	No. of units
Solar PV cells			
Photo sensitive semiconductor device	85414000	2007	286,285
Photo sensitive semiconductor device	85414000	2008	204,462
Photo sensitive semiconductor device	85414000	2009	206,896
Photo sensitive semiconductor device	85414000	2012	299,215
Photo sensitive semiconductor device	85414000	2013	402,42
Photo sensitive semiconductor device	85414000	2014	21,281
Photo sensitive semiconductor device	85414000	2015	389,081
Photo sensitive semiconductor device	85414000	2016	435,569
Photo sensitive semiconductor device	85414000	2017	1,823,710
Photo sensitive semiconductor device	85414000	2018	961,597
Photo sensitive semiconductor device	85414000	2019	260,133
Photo sensitive semiconductor device	85414910	2020	15,910,980
Solar PV Modules	85414910	2021	62455
Solar PV Modules	85414910	2022	6759
Batteries			
Battery parts	85069000	2007	472118
Battery parts	85069000	2008	1151107
Battery parts	85069000	2009	9104921
Lead-acid accumulators	85071000	2012	477101
Lead-acid accumulators	85072000	2013	489,028
Lead-acid accumulators	85072000	2014	79,206
Tubular Battery for Solar	85072000	2015	79,036
Tubular Battery for Solar	85072000	2016	445,614
Tubular Battery for Solar	85072000	2017	326,166
Lead-acid accumulators	85071000	2018	434876
Lead-acid accumulators	85072000	2019	256255
Lead-acid accumulators	85072000	2020	508030
Lead-acid accumulators	85072000	2021	435240
Lead-acid accumulators	85072000	2022	20924
Solar charge controller			
Solar equipments	85412900	2007	3,034
Solar equipments	85412900	2008	245,721
Solar equipments	85412900	2009	41,727

Solar equipments	85412900	2014	11,084
Solar equipments	85412900	2015	15,780
Solar charge controller	85044000	2016	3,271,634
Solar charge controller	85044000	2017	5,746,753
Solar charge controller	85044090	2018	205,898

7.2 Annexe II

Table 11: Solar PV system deployment data from 2002-2021

Installed solar PV systems	Year	Unit	No. of units
Solar home systems	2002	Nos.	1160
	2003	Nos.	11840
	2004	Nos.	14284
	2005	Nos.	17887
	2006	Nos.	6788
	2007	Nos.	6690
	2008	Nos.	34755
	2009	Nos.	60502
	2010	Nos.	36135
	2011	Nos.	57059
	2012	Nos.	35627
	2013	Nos.	96495
	2014	Nos.	87038
	2015	Nos.	103161
	2016	Nos.	56770
	2017	Nos.	16084
	2018	Nos.	208,368
	2019	Nos.	60,454
	2020	Nos.	50,828
	2021	Nos.	12,076
Institutional solar PV system	2010	Nos.	796
	2013	Nos.	563
	2018	Nos.	393
	2019	Nos.	1,037
	2020	Nos.	19
	2021	Nos.	1018
Urban solar home system	2018	Nos.	21144
Solar drinking water and irrigation pump	2007	Nos.	24
	2008	Nos.	5
	2009	Nos.	5
	2010	Nos.	30
	2012	Nos.	47
	2018	Nos.	375
	2019	Nos.	878
	2020	Nos.	1082
	2021	Nos.	682
Solar mini grid	2018	kW	1
	2019	kW	150
	2020	kW	699
	2021	kW	1667

7.3 Annexe III

Table 12: Typical system sizes assumed for e-waste projection

	Panels			Battery inverter			Solar pump inverter			Grid-tied inverter			Battery		
	25 years			10 years			10 years			10 years			5 years		
	Size	Pcs	Weight (kg)/unit	Size	Pcs	Weight (kg)/unit	Size	Pcs	Weight (kg)/unit	Size	Pcs	Weight (kg)/unit	Size	Pcs	Weight (kg)/unit
Solar home system	100Wp	1	8	100W	1	0.5							480Wh	1	14
Institutional solar PV system	325Wp	6	22	1500W	1	15							2400Wh	4	69
Urban solar home system	325Wp	3	22	700W	1	9							2400Wh	2	69
Solar drinking water and irrigation pump	325Wp	4	22				1000W	1	5						
Solar mini-grid	325Wp	185	22	4600W	6	63				25000W	2	61	2000Wh	144	80

7.4 Annexe IV

Table 13: Year-wise volume of e-waste based on AEPC's deployment data

			Year																					
			2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
SHS	*Systems installed*	nos.	1,160	11,840	14,284		17,887	6,788	6,690	34,755	60,502	36,135	57,059	35,627	96,495	87,038	103,161	56,770	16,084	208,368	60,454		50,828	12,076
	Panels	MT	9	95	114	0	143	54	54	278	484	289	456	285	772	696	825	454	129	1,667	484	0	407	97
	Battery inverter	MT	1	6	7	0	9	3	3	17	30	18	29	18	48	44	52	28	8	104	30	0	25	6
	Battery	MT	16	162	196	0	245	93	92	477	830	496	783	489	1,323	1,194	1,415	779	221	2,858	829	0	697	166
ISPS	*Systems installed*	nos.										796			563					393	1,037		19	1,018
	Panels	MT										105			74					52	137		3	134
	Battery inverter	MT										12			8					6	16		0.3	15
	Battery	MT										218			154					108	284		5	279
USHS	*Systems installed*	nos.																		21,144				
	Panels	MT																		1,396				
	Battery inverter	MT																		190				
	Battery	MT																		2,900				
SWP	*Systems installed*	nos.							24	5	5	30		47						375	878		1,082	682
	Panels	MT							2	0.4	0.4	3		4						33	77		95	60
	Solar pump inverter	MT							0.1	0.03	0.03	0.2		0.2						2	4		5	3
SMG	*Systems installed*	kW																			150		699	1,667
	Panels	MT																			10		47	113
	Battery inverter	MT																			2		10	23
	Grid-tied inverter	MT																			0		2	4
	Battery	MT																			29		134	320

SHS: Solar Home Systems ISPS: Institutional Solar Power Systems USHS: Urban Solar Home System
SMG: Solar Mini-Grids SWP: Solar drinking water and irrigation pump