

BATTPRO – Final Report

Battery takeback professionalization to support environmental protection in Cambodia

Cambodia

67EXI7001

Stiftung GRS

ECOLOGICON
circular economy & consulting

Supported by:

Federal Ministry
for the Environment, Climate Action,
Nature Conservation and Nuclear Safety

based on a decision of
the German Bundestag

Forewords

Portable batteries are now part of everyday life in Cambodia. They power mobile phones, remote controls, tools, household appliances and a growing range of small electronic devices. Yet once these batteries reach the end of their useful life, they are still rarely collected through clear, traceable channels. This practical gap was the starting point for BATTPRO. A growing battery market needs a take-back system that is safe, affordable and suited to local conditions. The project therefore links directly to environmental protection, climate action and the Sustainable Development Goals, particularly those related to responsible consumption, health, clean cities and the circular use of resources.

The situation in Cambodia shows why this issue should be addressed now. Formal collection options for portable batteries are still limited. Many batteries are disposed of with ordinary household waste, stored without a secure treatment route, or handled through informal channels. If damaged or managed improperly, they can cause fires and release substances that may affect soil, water, air quality and occupational safety. At the same time, limited reporting makes it difficult to determine how many batteries enter the market, where they are used and what happens to them after disposal.

BATTPRO was implemented by Foundation GRS and ECOLOGICON GmbH, with funding from the Environmental Protection Export Initiative of the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety. The project combined practical experience in battery take-back systems, producer responsibility and circular economy consultancy. Its work included stakeholder mapping, market and material-flow analysis, collection and downstream scenarios, an indicative economic model and a roadmap for the gradual professionalisation of portable battery management in Cambodia.

The topic is closely linked to Cambodia’s wider economic development. Rising incomes, urban growth and better access to electrical and electronic devices all increase the number of batteries entering the market. Without a corresponding expansion of collection, storage, transport and treatment capacities, end-of-life batteries and battery-powered devices will place additional pressure on existing waste-management structures. Addressed early, battery take-back can reduce environmental and fire risks, improve data transparency, create local service opportunities and support Cambodia’s transition towards a more circular economy. This paper presents the evidence, scenarios and implementation steps developed under BATTPRO.

Who we are

Foundation GRS and ECOLOGICON GmbH are the key partners leading the BATTPRO project, supported by funding from the German Federal Ministry for the Environment, Climate Protection, Nature Conservation and Nuclear Safety (BMUKN).

As a foundation, Foundation GRS is an independent, non-profit competence centre for Extended Producer Responsibility (EPR) and battery circular economy, combining practical experience with research, system development and international knowledge transfer.

ECOLOGICON GmbH specializes in circular economy consultancy and sustainable waste management, bringing extensive experience in developing and implementing environmental solutions across various industries.

Together, with the financial and strategic backing of BMUKN, the partners combine their knowledge and capabilities to address pressing environmental challenges related to battery waste management.

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Executive Summary

The Cambodian battery market is entering a phase in which end-of-life management can no longer be treated as a marginal issue. Portable batteries are used in a growing range of household devices, small appliances, tools and electronic products. With rising incomes, urban growth and broader access to electrical equipment, the quantities placed on the market are expected to increase further. BATTPRO estimates that imports of portable and replaceable batteries could reach about 3,125 Mg per year by 2035, around 80 % above the current baseline. If collection and treatment structures remain at current levels, more end-of-life batteries will enter unmanaged waste streams, increasing risks to public health, the environment and fire safety.

BATTPRO responds to this situation by looking at what would be needed for a workable take-back system under Cambodian conditions. The project, implemented by Foundation GRS and ECOLOGICON GmbH with funding from the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety, combined market analysis, stakeholder work, material-flow modelling, downstream scenarios and an economic assessment. Its purpose was not to design a perfect final system on paper, but to identify practical steps that can move Cambodia from a small collection base to-wards a safer and more reliable battery management structure.

At present, formal collection is still limited. ECOBATT Energy Cambodia operates the main visible collection scheme, especially in Phnom Penh, but it captures only a small fraction of the total portable battery waste stream. Large quantities are likely to remain in household waste, pass through informal-sector routes, end up in landfills or dumpsites. Cambodia has started to address producer responsibility in its wider environmental and waste-management framework, including recent EPR-related obligations. However, portable batteries still lack key system elements: a producer or importer register, reliable placed-on-market reporting, binding take-back duties, stable financing, and verified treatment standards.

To support policy development, BATTPRO analysed the potential costs of a future battery EPR system. The fee modelling provides an important indication for policy design. On the assumptions used in BATTPRO, the annual system costs could be covered with a comparatively small fee per battery if all batteries placed on the market contribute. The modelling suggests that the required EPR fee required to cover the system costs would range from approximately USD 0.002 to USD 0.006 per battery, depending on the collection and system development scenario. This corresponds to about 0.4 to 1.4 % of the assumed average battery price. These values are indicative estimates of the expected order of magnitude, not final tariff proposals. They should be reviewed and recalculated once data from actual system operation become available, including information on market volumes, collection performance, transport and export costs, treatment costs, material revenues and administrative expenditure.

The proposed roadmap is therefore deliberately staged. In the short term, the priority is to make the system manageable, clarify responsibilities, test collection points with high expected return volumes, introduce basic reporting, improve storage conditions and prepare safe logistics and export routes. The medium-term task is to turn these pilots into an enforceable EPR framework with clear obligations for importers and distributors, a producer register, financing flows, audits and national sorting or pretreatment capacity. In the long

term, Cambodia can move towards wider collection coverage, digital tracking, binding collection and recycling targets and stronger links to secondary raw material markets. Domestic or regional recycling should remain part of the discussion, but only where sufficient volumes, safety standards, permitting conditions and market outlets can support it.

1 Introduction and Objectives

Portable batteries are ubiquitous in households. They power our smartphones, smartwatches, remote controls, laptops, power tools and many other mobile electrical devices. Some are replaceable, while others are built into rechargeable devices. Depending on their application, batteries vary widely in capacity, chemistry, shape and size. Larger, higher-capacity batteries are also used in electric vehicles, solar storage systems and residential energy storage. According to a report by the World Economic Forum and Global Battery Alliance (2019), global battery demand is projected to rise from 184 GWh in 2018 to more than 2,624 GWh by 2030—an increase of over 1,400 % in 12 years (World Economic Forum [WEF] & Global Battery Alliance, 2019). Growth is mainly driven by the electrification of mobility (26 % compound annual growth rate—CAGR) and energy storage systems (38 % CAGR), while demand for batteries used in consumer electronics is projected to increase from 38 GWh to 69 GWh, equating to a 5 % CAGR. A more recent projection by McKinsey & Company and Global Battery Alliance (2023) estimates global battery demand at approximately 4,700 GWh by 2030, indicating that market growth may exceed earlier expectations.

The following figure provides an overview of battery demand between 2018 and 2030, broken down by region.

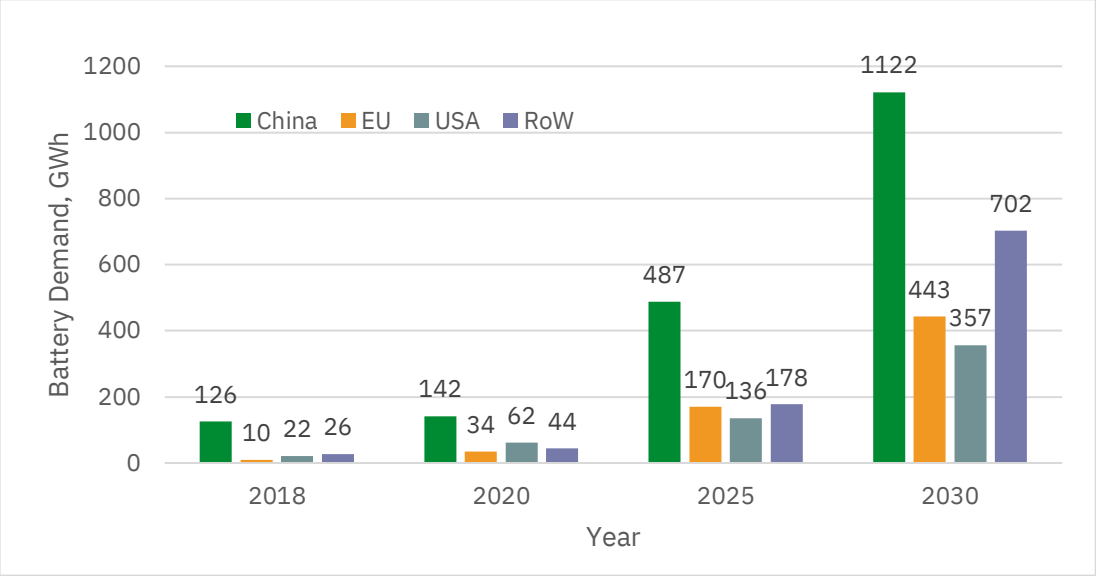


Figure 1: Global battery demand by region from 2018 to 2030. (World Economic Forum and Global Battery Alliance, 2019)

As battery demand grows, battery waste increases accordingly. However, waste generation lags market placement because battery lifespans vary considerably. Low-quality, single-use zinc-carbon batteries may last only a few hours, rechargeable laptop batteries typically four to five years, and electric-vehicle batteries even longer. The shorter the use phase, the sooner a battery becomes waste. The BATTPRO project focused solely on portable device batteries in the Cambodian market. Solar power storage systems, electric-vehicle batteries, lead-acid batteries and starter batteries used in cars were outside the scope of the project.

Batteries contain heavy metals and other toxic solid and liquid substances, posing serious environmental and health risks if they are not collected at end of life (EOL). Littered batteries can contaminate soil and freshwater, pollute the air and harm wildlife. Improperly disposed

batteries can also pose a serious fire hazard for municipal waste collection and landfills if they are damaged during waste management processes because of their high reactivity at EOL. If toxic substances enter the food chain, they may cause respiratory problems, disrupt hormones, increase cancer risk and reduce life expectancy.
Effective take-back at EOL is therefore essential. Many countries have introduced battery take-back systems and extended producer responsibility (EPR) regulations to finance safe collection and downstream treatment. Although EOL batteries may contain valuable materials, recovering them is capital-intensive, and their material value alone does not cover the associated costs. External financing through an EPR system is therefore necessary. Where EPR legislation is absent, rudimentary or unclear, responsibilities remain undefined and financing gaps persist. As a result, EOL batteries may be littered, dumped in the environment or, where municipal collection exists, disposed of in landfills.
The BATTPRO project— "Battery Take-Back Professionalisation to Support Environmental Protection in Cambodia"—assessed the current market situation for portable batteries in Cambodia and developed a roadmap for improved battery waste management through 2035. The project partners were Stiftung Gemeinsames Rücknahmesystem Batterien, an independent non-profit competence centre for EPR and battery circular economy, and ECOLOGICON GmbH, a German consultancy specialising in waste management and the circular economy. The project ran from August 2024 to July 2026 and was funded by the Environmental Protection Export Initiative of the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN).

The BATTPRO project objectives are closely aligned with its planned work packages. The following table provides an overview of the BATTPRO work packages.

Table 1: Overview of BATTPRO project work packages.

Work Package No.	Work Package Content
1	Desktop research for stakeholder identification and outreach and status quo evaluation
2	Market analysis through external experts
3	Identification of collection and recycling infrastructure and battery material flow modelling
4	Identification of downstream system options besides technology providers
5	Economic evaluation and identification of best practices
6	Communication, dissemination and exploitation
7	Project Management

The following objectives were to be fulfilled within the scope of the project:

- Map key stakeholders in the battery and WEEE sector
- Analyse the market structure, legal framework, and informal sector
- Develop a material flow model for waste batteries
- Identify and assess technological downstream options
- Evaluate economic feasibility and derive a financial plan

- Develop a roadmap for improved battery waste management
- Provide recommendations and implementation pathways for EPR systems

This white paper summarises the project's key results, including the current state of battery waste management in Cambodia, the projected battery waste volumes for 2035, the process scenarios, and the economic model used to estimate EPR fees. It also presents a roadmap for improving battery waste management across short-, medium-, and long-term horizons, together with cross-cutting factors critical to successful implementation.

2 Methodology and Data Basis

Data collection and stakeholder mapping

The first part of the project focused on developing a comprehensive overview of the current situation of portable batteries in Cambodia. To establish this baseline, the project team analysed available trade data as well as publicly available scientific and governmental information on the use of portable batteries in Cambodia and Southeast Asia.

In parallel, the team conducted a detailed stakeholder analysis. This served two main purposes: to gain better access to the Cambodian battery market and to identify the key actors involved in the sector. Most stakeholders were approached during the project and informed about the project's goals.

Expert input

After identifying and contacting the relevant stakeholders, the project team engaged Cambodian experts to support a targeted research study. The study focused on three guiding questions:

- How many batteries are on the market, and where do they end up after use?
- Which legal frameworks regulate the sale, use, collection and downstream processing of portable batteries in Cambodia?
- Is the informal sector actively collecting and/or processing portable batteries in any way?

Material flow modelling

Based on the findings from the research phase and the local experts' reports, the project team developed a material flow model for Cambodia's battery waste sector. The model estimates how many portable batteries become waste each year and illustrates where these batteries go after reaching EOL in Cambodian households.

Stakeholder workshop for scenario development

Building on the research questions and the developed material flow model, the project team approached Cambodian stakeholders to conduct a workshop on the future of battery waste management in Cambodia.
During the workshop, stakeholders from policy, development organisations and the Cambodian waste management sector went through a guided process to discuss different battery waste management options for the country that could realistically be implemented until 2035.

Based on the feedback collected during the workshop, the project team developed three scenarios for the future of battery waste management in Cambodia:

- a baseline scenario,
- a realistic implementation scenario, and
- a best-case scenario.

Process design and output assessment

For each scenario, the project team developed a corresponding downstream process flow. The scenarios were then assessed based on their expected outputs, including:

- the amount of waste generated,
- the volume of secondary raw materials recovered, and
- the reduction of landfilling compared to the baseline scenario.

Financial assessment and EPR fee calculation

In the final step, each process scenario was financially evaluated. The purpose of this assessment was to estimate the EPR fee that would need to be charged to importers to cover the costs of each scenario.

3 Current Status of the Battery Market in Cambodia

During the start of the project, the project team assessed the status quo of battery waste management in Cambodia. This involved identifying and contacting relevant stakeholders through a stakeholder analysis process as well as identifying regulations addressing batteries and battery waste in Cambodia. To gain an overview on trade flows of battery containing devices as well as possible material flows, trade statistics and material flow analysis were reviewed. The results of these steps are displayed in the following four chapters.

3.1 Regulatory Framework

Cambodia's Law on Environmental Protection and Natural Resource Management (1996) tasked the MoE as the leading agency for formulating policies, issuing regulations and coordinating waste management and pollution control actions. In 2008, the MoE developed Cambodia's interpretation of the 3R (reduce, reuse, recycle) strategy, supported by the United Nations Environment Programme (UNEP 2017). Several regulations, guidelines and initiatives have been developed over the past two decades. However, the lack of monitoring and implementation capacities remains the major challenge. According to current regulations, municipalities and provinces are responsible for collecting, transporting and disposing of waste. Sub-Decree No. 36 on Solid Waste Management, of 1999, stipulates that the collection, transportation, recycling, minimization and dumping of waste in provinces and cities is the responsibility of provincial and city authorities. Sub-Decree No. 113 on Management of Garbage and Solid Waste of Downtowns from 2015 confirms this administrative organizational structure. The provincial level used to oversee solid municipal waste management but due to its range of responsibilities, the Cambodian Government was encouraged to fully involve the municipalities.
Sub-Decree No. 16 on Electrical and Electronic Equipment Waste Management was implemented in 2016 to prevent the disposal of E-waste into rivers or dumps by stipulating penalties for individuals and businesses. The MoE introduced Sub-Decree No. 138 on the Management of Plastic Bags in 2017 requiring supermarkets and shopping malls to charge customers 400 riels (about US$ 0.10) per bag. The goal is to change consumer behaviour. As a result, the distribution of plastic bags by supermarkets has been reduced by 30 %. The MoE has also considered introducing a complete ban on plastic bags but acknowledges that implementing it would be extremely difficult.

A new sub-decree to regulate single-use plastics and foam containers is currently being formulated by the MoE, with the support of the United Nations Development Programme, the World Bank and the National Waste Management taskforce. The new regulation aims to reduce the use of plastic bags, straws and styrofoam containers, to find sustainable alternatives to single-use plastics and to raise consumer awareness of the subject. The use of economic incentives and self-regulation instruments have so far not been implemented to any significant degree. Many factories have no internal policy on waste management. There are no specific incentives available for companies that wish to develop initiatives to implement

the 3R strategy.
Sub-Decree No. 124 on Tax Incentives for Small and Medium-Sized Enterprises operating in defined priority sectors came into effect in October 2018. Waste processing for the tourism sector is one of the priorities. The authorities have also established a list of supplies that are exempt from value-added tax, in line with the 2017 Law on Financial Management. The term 'supplies' refers to both services and goods.

With the adoption of Prakas No. 2196/0325 on 18 March 2025, Cambodia established specific responsibilities for producers, importers and exclusive suppliers of electrical and electronic equipment once these products reach their end-of-life. The regulation requires obligated entities to organize and ensure the environmentally sound collection, transportation, sorting, labeling, storage and treatment of waste electrical and electronic equipment (WEEE). In addition, requirements for the documentation and reporting of relevant product and waste flows were introduced.

The Prakas also established a mandatory semi-annual reporting obligation to the Ministry of Environment. Producers, importers and exclusive suppliers are required to report quantities of imported electrical and electronic equipment as well as quantities of collected end-of-life equipment every six months.

The scope of the regulation explicitly covers both primary and secondary batteries listed in Annex 1, including non-rechargeable batteries, rechargeable accumulators and lithium-ion batteries. Consequently, the obligations established under the Prakas are directly applicable to end-of-life batteries.

The regulation operationalizes the provisions of Article 254 of the Code of Environment and Natural Resources, which requires the collection and environmentally sound management of hazardous waste. To fulfil their obligations, companies may establish their own collection systems or cooperate with service providers authorized by the Ministry of Environment. The environmentally sound treatment of collected waste is likewise mandated.

By assigning end-of-life management responsibilities to producers and importers, the Prakas introduces key elements of an Extended Producer Responsibility (EPR) approach into Cambodia's regulatory framework. For batteries in particular, it creates a legal basis for extending responsibility beyond product placement on the market to the collection and management of waste batteries. While the regulation establishes collection, treatment and reporting obligations, it does not yet define other elements commonly associated with mature EPR systems, such as financing mechanisms, collection targets or recycling performance requirements.

Information on the practical implementation of the regulation remains limited. No publicly available evidence could be identified indicating that the mandatory semi-annual reporting system has already been routinely implemented, systematically evaluated by the responsible authorities, or supported by established enforcement activities. As a result, the effectiveness of the new regulatory framework cannot yet be assessed.

Key Laws and Policies:

- Solid Waste Management Sub-Decree (1999)
- Sub-Decree 16 (2016) – Covers EEE & e-waste management.
- Prakas No. 387 (2015) – Toxic substance disposal limits.
- Prakas 2196/0325 (March 2025) – Introduces EPR obligations for manufacturers, importers, and suppliers.

- Basel Convention (ratified 2001) – Cambodia complies but has not ratified the Ban Amendment (2005).
- Code of Environment (2023) – Requires permits for waste activities and outlines reporting duties.

3.2 Stakeholder Analysis

During the BATTPRO project, the following formal private-sector stakeholders were identified as particularly relevant for Cambodia's e-waste and battery waste management landscape:

- **Chipmong Insee Ecocycle:** Chipmong Insee Ecocycle is a subsidiary of Chipmong Insee Cement Corporation, exploring co-processing of battery waste in cement kilns. The company is assessing the feasibility of using battery materials like carbon or plastic casings as alternative fuels or raw materials in cement production. It contributes to the downstream segment by offering a potential domestic solution for hazardous waste disposal, particularly for parts of non-recyclable battery fractions.
- **CINTRI Cambodia:** One of the largest and longest-established solid waste management companies in Cambodia. It currently operates waste collection services in Phnom Penh districts and other cities.
- **Crown Workspace:** Crown Workspace Cambodia focuses on sustainable office relocations and IT asset lifecycle management. It collects used electronics from B2B clients and channels them into reuse or recycling streams, often partnering with certified recyclers like TESS AMM. Crown Workspace contributes to the upstream segment by facilitating responsible disposal and reuse of WEEE from commercial sources.
- **Ecobatt Energy Cambodia Ltd.:** Ecobatt Energy Cambodia is the country's only licensed e-waste recycler, operating a nationwide battery take-back system since 2019. It collects used batteries and Powerbanks via disposal bins in Phnom Penh and other provinces. Batteries collected by the company are stored as a mixed waste fraction in plastic barrels as no downstream operation for these battery fractions is available in the country.
- **800 Super-GAEA:** Municipal solid waste collection and transport company which operates in several Phnom Penh districts through a government concession. It is a joint venture between Singapore's 800 Super and Cambodian GAEA.
- **Mizuda Sanitation Cambodia:** Municipal solid waste collection operator and increasingly active in waste sorting, recycling, AI-supported waste management, and waste-to-energy initiatives. The company has a long-term cooperation framework with the Ministry of Environment.
- **TESS AMM:** TESS AMM Cambodia is a branch of the global TESS-AMM Group, known for IT asset disposition and secure e-waste recycling. In Cambodia, TESS AMM provides dismantling, data destruction and material recovery services for B2B clients.
- **Verywords Cambodia:** Verywords Cambodia is a Korean company involved in electric mobility solutions. They produce and sell electric scooters in Cambodia and plan to preprocess their own lithium-ion batteries at their end-of-life and export the preprocessed materials to Korean companies for recycling. They are currently setting up their preprocessing facility in Phnom Penh.
- **Virak Recycle:** Virak Recycle is a Cambodian-owned and -operated company providing professional services in scrap trading (iron, steel, stainless steel, aluminium, copper and

lead-acid batteries), used machinery trading and the demolition of buildings, factories and warehouses in Cambodia. The company mainly acts as a dealer and dismantler of metal scrap but has no experience in the downstream treatment of WEEE or waste batteries.

- **Country context:** Cambodia is in Southeast Asia on the Indochina Peninsula and borders Laos to the north, Thailand to the west, Vietnam to the east and the Gulf of Thailand to the southwest. The country covers an area of around 181,000 km². The population is about 17.8 million people, which corresponds to a population density of about 95 inhabitants per km². Nominal gross domestic product (GDP) was recently around USD 51.3 billion, with a GDP per capita of about USD 2,870. According to the World Bank's classification, Cambodia is one of the lower-middle-income countries (United Nations [UN], 2024; World Bank Group, 2026)

3.3 Trade Flow Analysis

The following graphics provide an overview of the battery market in Cambodia. Import and export data for the base year 2022 were extracted from the UN Comtrade database by way of example (UN, 2025). The year 2022 was selected as the base year because the available UN Comtrade records for Cambodia appeared more complete and consistent than the more recent reporting years at the time of analysis. Incomplete data were extrapolated using average data from ASEAN countries.

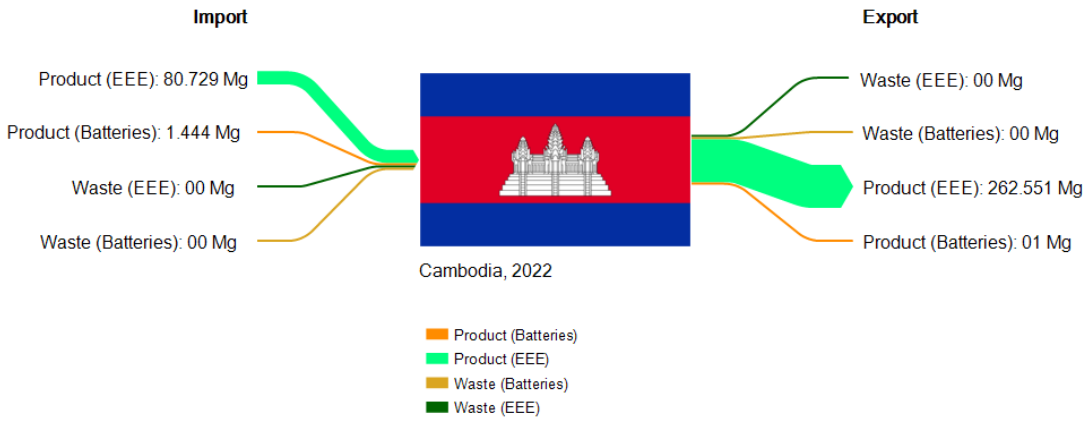


Figure 2: Overview of imported and exported (W)EEE and (Waste) batteries in Cambodia 2022.

- Figure 2 shows that Cambodia imported 80,729 Mg of EEE and 1,444 Mg of portable batteries in 2022. It is unclear whether certain devices included in the EEE stream contain portable batteries. The high export mass of EEE (262,551 Mg) suggests that Cambodia has domestic EEE production capacity that may use imported batteries and subsequently export them after the production or assembly process is completed. No imports or exports of (W)EEE or waste batteries were reported. Less than 1 Mg of batteries was re-exported.

The following figure provides an overview of imported batteries and accumulators in 2022, 2023 and 2024. The quantities of primary cells, batteries and electric accumulators vary between years. Averaging the imported battery masses over three years results in an annual average imported mass of 557 Mg of electric accumulators and 1,190 Mg of primary cells and batteries (5,421 Mg in total over three years).

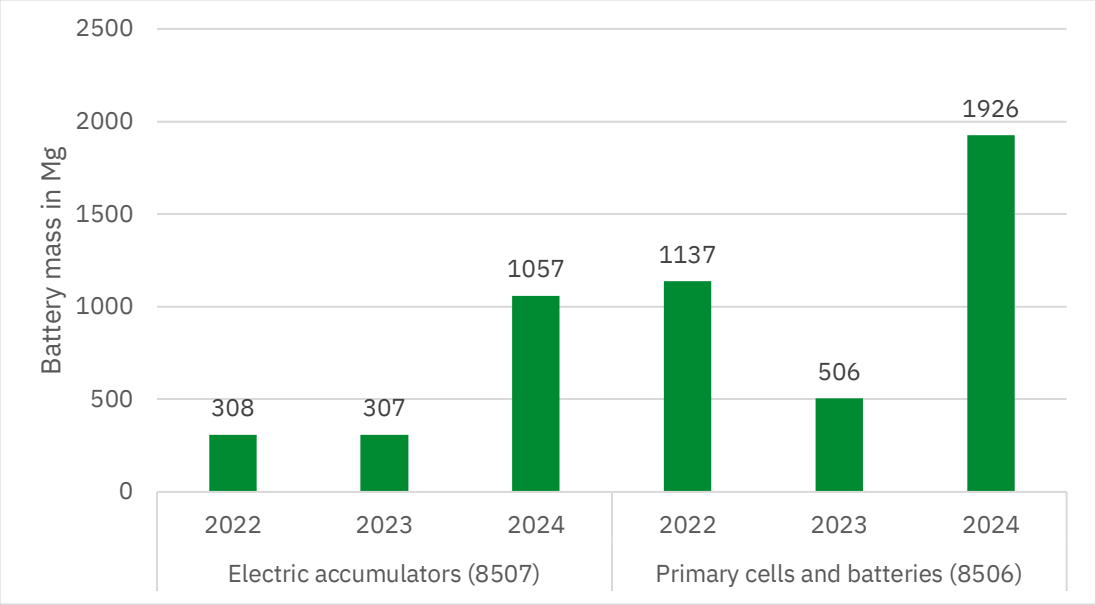


Figure 3: Overview of imported battery mass 2022-2024.

The following figure displays the market distribution between the different battery chemistries. Lead acid batteries were not included in the research as they were out of the scope of the project.

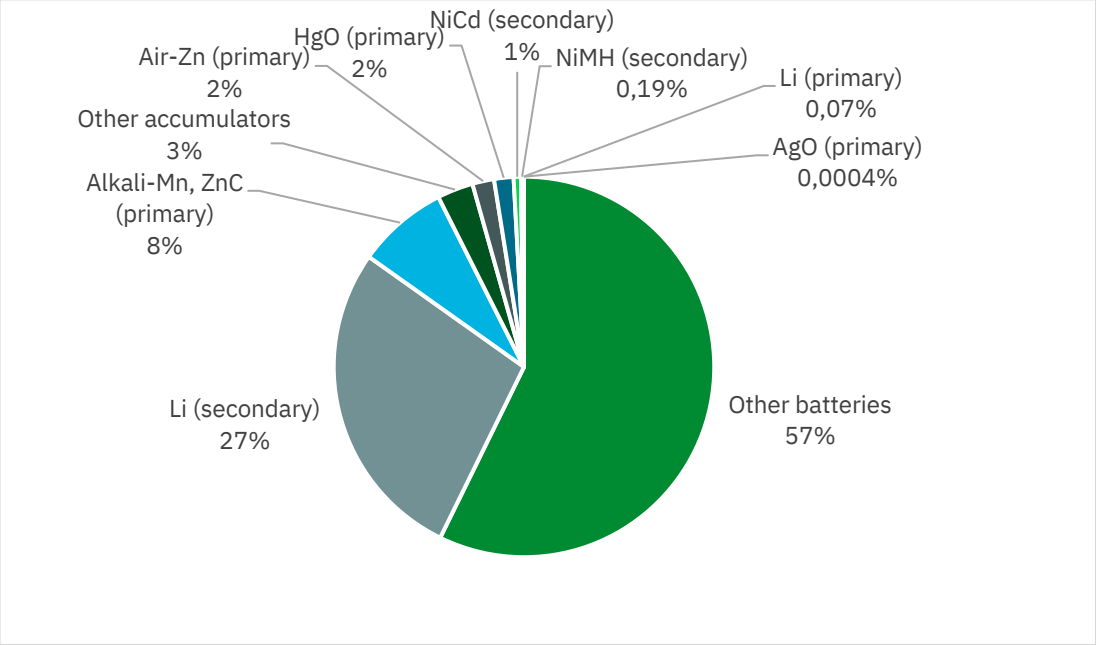


Figure 4: Battery chemistry distribution for imported batteries between 2022 and 2024.

The category “Other batteries” includes HS code 850680 – "Primary cells and primary batteries, other" and refers to non-rechargeable batteries that do not fit into more narrowly defined categories under the primary battery classification. HS code 850680 is a residual category for primary cells and primary batteries that are not covered by more specific subheadings. In principle, common battery chemistries such as manganese dioxide, lithium primary, silver oxide and air-zinc cells should be reported under their respective specific HS subheadings. However, in practice, shipments may still be declared under 850680 where the exact chemistry is unknown, documentation is incomplete, or mixed battery fractions are reported together. For market-size estimates, 850680 should therefore be interpreted

as a residual and potentially mixed reporting category rather than as a technically precise chemistry category.

The category “Other accumulators” includes HS code 850780 – "Other electric accumulators" refers to a broad category of rechargeable batteries that are not specifically classified under other HS codes. HS code 850780 is a residual category for electric accumulators not covered by more specific subheadings. Lithium-ion, nickel-cadmium and nickel-metal hydride accumulators should generally be reported under their specific HS codes where correctly declared. In trade data, however, 850780 may still contain misclassified or insufficiently specified rechargeable batteries. It should therefore be treated as an uncertainty category and analysed together with the relevant specific accumulator codes when estimating market volumes.

Correct battery classification in international trade statistics remains a significant challenge. Battery products are often declared under generic or residual HS codes, such as 850680 (Other batteries) and 850780 (Other accumulators), when the exact battery chemistry is unknown, insufficiently documented or the shipment contains several different types of battery chemistries. This can lead to the misclassification of common battery types, including alkaline, zinc-carbon, lithium-ion, and NiMH batteries, resulting in inaccurate import and market data. Consequently, estimates of battery consumption, waste generation, and recycling potential may be distorted, particularly in countries where customs declarations are less detailed or inconsistently enforced.

When analysing trade data in countries such as Cambodia, care should be taken when interpreting battery-related HS codes. In practice, customs declarations are often incomplete, and batteries may be reported under residual or "other" categories rather than the technically correct battery chemistry. As a result, common primary batteries such as alkaline and zinc-carbon batteries may be recorded not only under HS 850610 (manganese dioxide batteries) but also under HS 850680 (other primary batteries). Similarly, rechargeable batteries that should be classified under HS 850760 (lithium-ion accumulators) may sometimes be reported under HS 850780 (other accumulators).

To reduce the risk of underestimating battery imports and future waste batteries, it is therefore recommended to analyse HS 850610 and 850680 together when estimating primary battery volumes, and HS 850760 and 850780 together when assessing rechargeable battery imports. This approach helps compensate for potential classification errors and provides a more robust estimate of the actual battery market size, particularly in countries where customs reporting practices and product documentation may be less detailed.

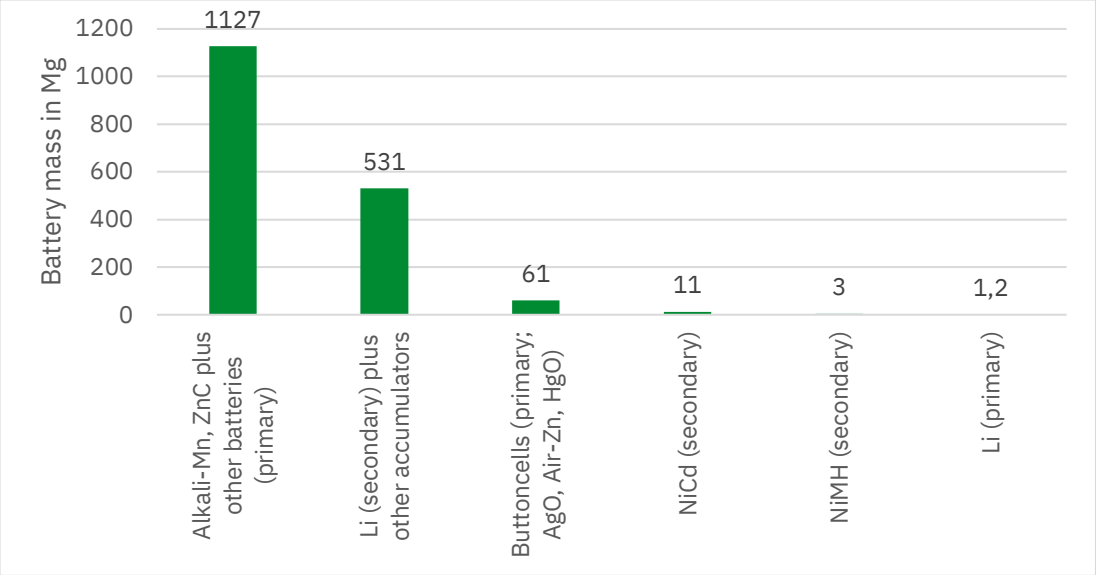


Figure 5: Imported yearly average battery mass based on battery chemistry between 2022 and 2024.

Figure 5 shows that Mercuric Oxide (HgO) batteries (86 Mg total between 2022 and 2024) categorised as button cells, were imported. These are banned or restricted heavily in many countries worldwide. In the European Union (EU) for example these batteries are basically banned, as the maximum amount of mercury content allowed for batteries is 0,0005 %. Mercury containing batteries are used in different sectors (e. g. Medicine and Military) as they are considered reliable with high energy density and consistent in voltage over long periods. Additionally the figure shows, that Cambodia imported Nickel-Cadmium (NiCd) batteries (32 Mg total between 2022 and 2024) which are banned to be sold in consumer products like power tools in the EU since 2017 and banned since 2025 also for portable batteries due to their toxic cadmium content. Despite increasing restrictions—especially in the EU—NiCd batteries remain in use across several sectors (Aerospace, B2B applications, Military etc.) due to their durability, fast charging, and resilience in extreme conditions.

3.4 Material Flow Analysis

In developing the framework for the material flow analysis (MFA) performed in the BATTPRO project, particular attention was given to differentiating between battery types based on their application context and physical integration into devices, with the aim of accurately reflecting the diversity of sources contributing to the national battery stream. This nuanced categorisation enabled a more precise mapping of battery flows from point of entry to end-of-life management, serving as a foundation for identifying intervention points to mitigate environmental risks. By integrating multiple data sources and methodological approaches, the model provides a comprehensive picture of the nationwide battery lifecycle, laying essential groundwork for the subsequent delineation of system boundaries and process mapping.

The research question addressed by the MFA was:

“How many portable batteries enter the Cambodian market annually through import, how many portable batteries are used by Cambodian households on a yearly basis and where do the batteries end up after their use-phase?”

The model is intended to fulfil the following objectives:

- Identify and quantify used battery types in Cambodian households
- Map disposal pathways of waste batteries after their use-phase
- Determine how many waste batteries end up in environmentally unsound treatment conditions.
- Build a model that enables the development of environmentally sound treatment scenarios
- Describe stakeholders active in the collection and treatment of waste batteries and WEEE

The data used for the MFA were collected by experts hired in Cambodia, Sevea Consulting Ltd., who conducted a one-month study on the use of portable batteries in Cambodia. The study evaluated market size and informal-sector involvement while also examining legal aspects of battery waste collection and processing. The experts developed a bottom-up approach to model the number of devices using or containing batteries in Cambodian households, combined with a survey of different stakeholders in Cambodia to gain insight into their use of portable batteries. The authors supplemented the results provided by Sevea Consulting Ltd. with their own assumptions, additional devices and further considerations for the model. A detailed description of the system used to perform the MFA can be found in the Annex.

The bottom-up market model should be interpreted as a conservative baseline estimate, as not all battery-containing devices could be included. A detailed overview of the devices whose usage habits were evaluated and the identified processes for the MFA can be found in the annex.

Additionally, the combination of household ownership rate, devices per household and urban use rates may contribute to an underestimation of market size. To increase clarity, it would be necessary to adapt the model by incorporating both household income structures and urbanisation data. Due to limited data availability, the authors used the urbanisation rate for certain devices, assuming that urban households generally have slightly higher monthly incomes than rural households, which should result in higher consumption rates in urban areas.

The model estimates a minimum market size of 24,010,000 devices using 31,000,000 portable batteries per year. The figure below shows their distribution by replaceability type.

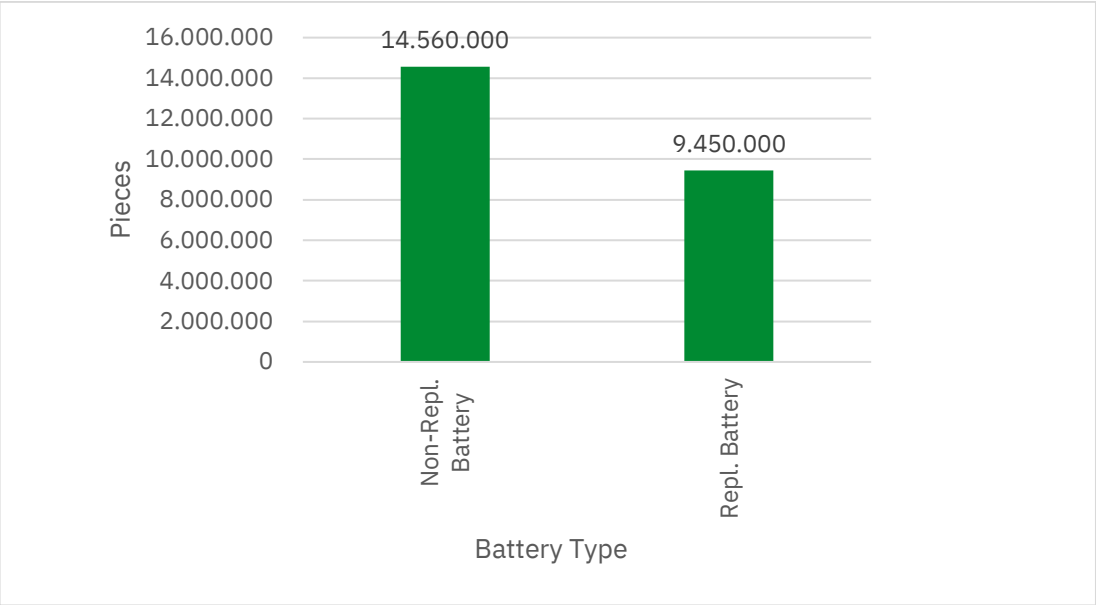


Figure 6: Number of devices in Cambodian households 2024.

The following figures display three different material flow models that were developed for the Cambodian battery market:

- **Material Flow Model for Replaceable Batteries:** This model encompasses individual battery cells, including common types such as AA, AAA, C, D, 9V batteries, and button cells. It primarily covers alkaline and zinc-carbon chemistries.
- **Material Flow Model for Non-Replaceable Batteries**: This model refers to battery packs and cells that are integrated within electrical and electronic devices and cannot be readily replaced by consumers. The primary chemistries included are nickel-metal hydride and lithium-ion.
- **Material Flow Model for the Complete Portable Battery Market:** This consolidated model brings together both replaceable and non-replaceable battery market segments.

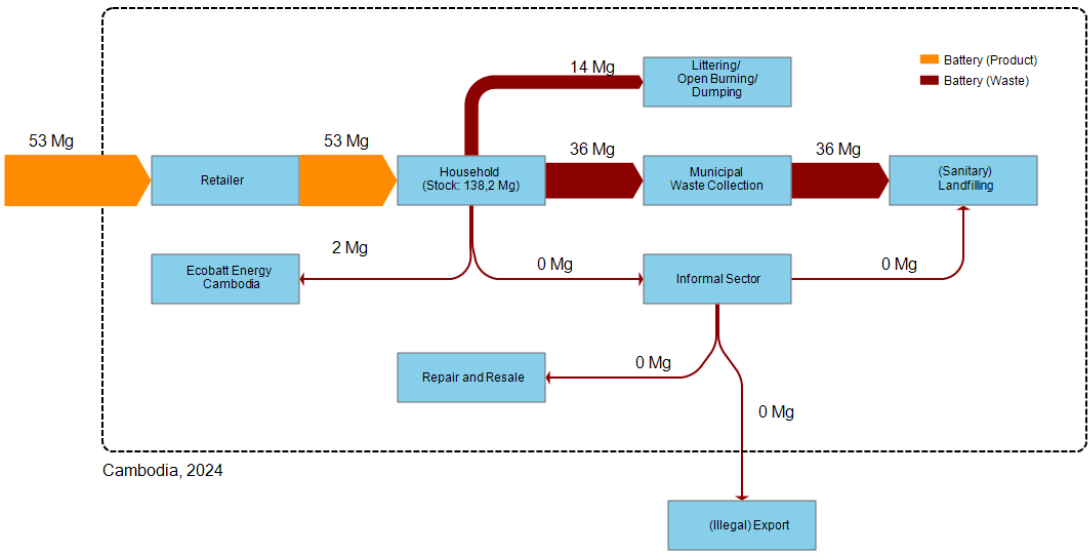


Figure 7: Material Flow Model for replaceable device batteries from households in Cambodia 2024.

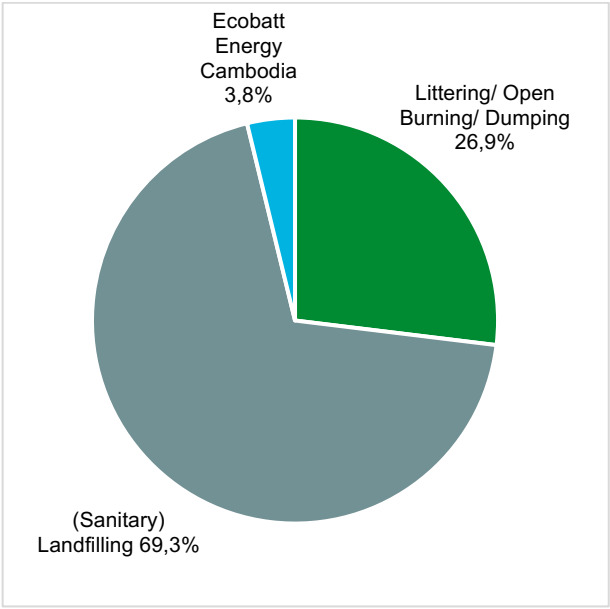


Figure 8: Final disposal pathways for replaceable batteries.

It is important to note that Ecobatt Energy Cambodia currently operates approximately 200 collection bins throughout Phnom Penh, collecting an estimated 3.8% of the annual waste batteries. This figure may in fact be lower, as the actual market size could exceed initial projections and the existing model assumes each battery is replaced immediately upon becoming waste. Consequently, the company has significant potential to expand its collection business by increasing both the number of collection boxes and public outreach initiatives. Presently, since many rural households remain outside the formal waste management system, around one quarter of annually generated waste batteries are disposed of through open burning sites or dumpsites, while approximately 70% of replaceable batteries are processed via municipal waste collection systems which then end up in (sanitary) landfills.

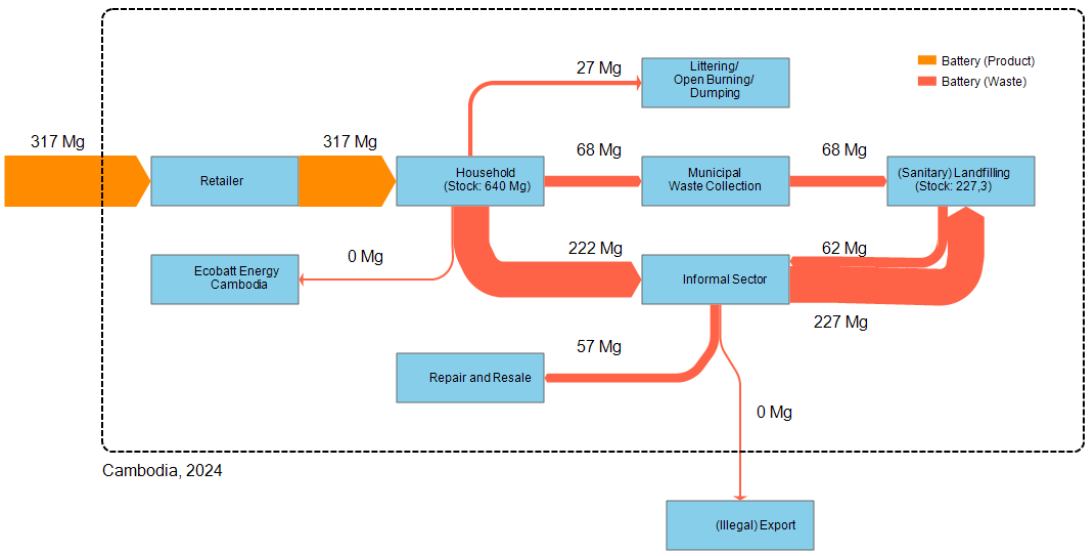


Figure 9: Material Flow Model for non-replaceable device batteries from households in Cambodia 2024.

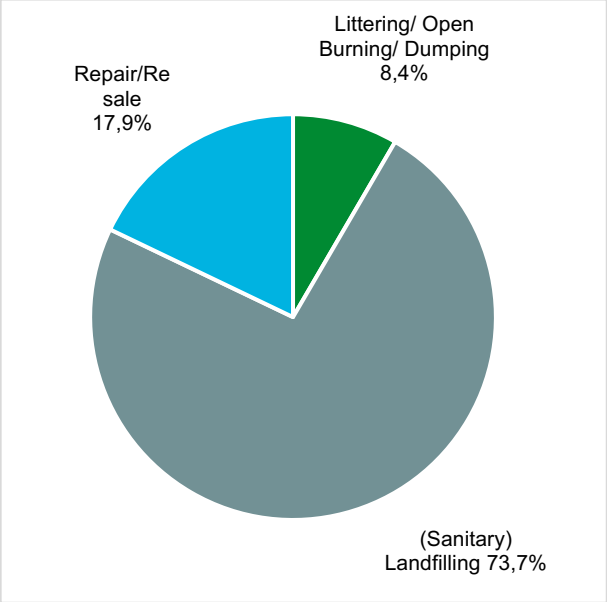


Figure 10: Final disposal pathways for non-replaceable batteries.

For non-replaceable batteries, a different picture emerges, as only 21.6 % of WEEE containing non-replaceable batteries ends up in municipal waste collection systems. Most of these battery types are disposed of through the informal sector. As no data on informal-sector activities were available, the amount of battery waste handled by informal actors is highly speculative. Because informal actors repair and resell some devices that become waste, an estimated 17.9 % are expected to enter a second use phase, while 73.7 % end up in sanitary landfills and 8.4 % enter environmentally unsound end-of-life pathways.

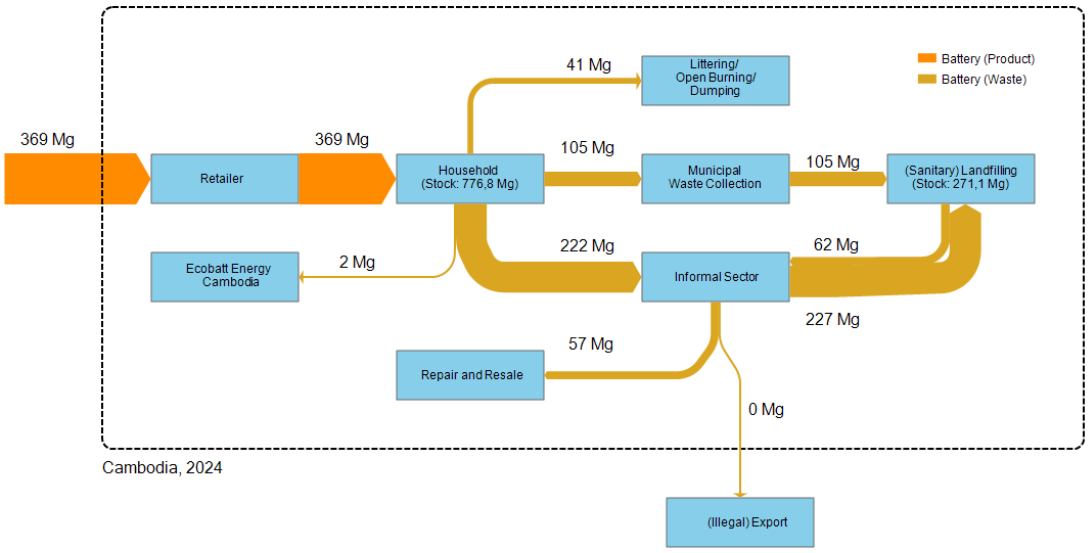


Figure 11: Material Flow Model for replaceable and non-replaceable device batteries from households in Cambodia 2024.

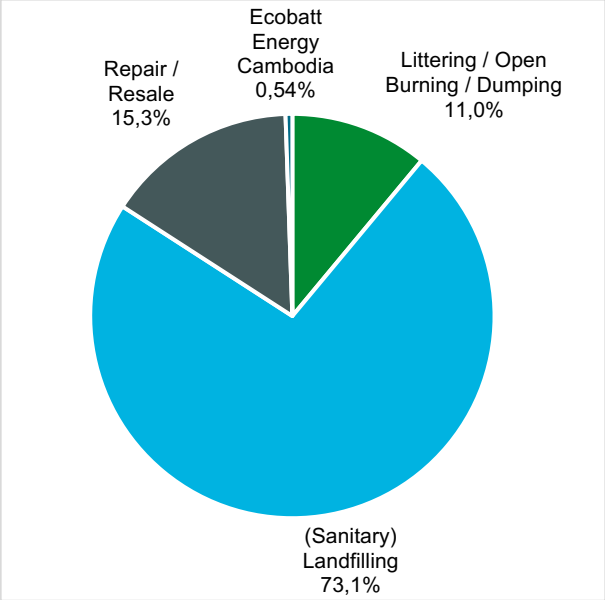


Figure 12: Final disposal pathways for all portable batteries.

The combination of the two material flow models produces the results shown in the figures above. According to this analysis, Ecobatt Energy Cambodia collects 0.5 % of the annual portable battery waste stream from households. Approximately 11 % of portable waste batteries are disposed of through methods considered environmentally unsound, such as littering and open burning, while 28.4 % enter municipal waste collection systems. The informal sector collects and processes 60.0 % of portable batteries. The informal sector acts as an important intermediate pathway for portable batteries and battery-containing devices. However, this does not necessarily imply environmentally sound final treatment. According to the model, a substantial share of batteries handled through informal-sector pathways ultimately ends up in landfilling or other disposal routes. For final disposal, (sanitary) landfilling remains the predominant pathway, accounting for 73.5 %. Due to repair activities conducted by informal sector participants, 15.3 % of portable non-replaceable batteries experience a second use phase.

Overall, the model results show a high degree of data uncertainty because there is no tracking or reporting of the number of batteries placed on the market each year. Import figures indicate market size, but because the contexts in which imported batteries are used are unclear, the results can provide only a snapshot of the lower range of battery use in Cambodia. Some imported batteries are probably built into devices that are sold on the Cambodian market or exported as electrical and electronic equipment. Some batteries may also be used in military, medical or business-to-business contexts that are outside the focus of this study.

A visualisation of battery waste by province and the locations of the collection points currently operated by ECOBATT Energy Cambodia can be seen in the following figure. The darker the green colour, the higher the annual battery waste generation.

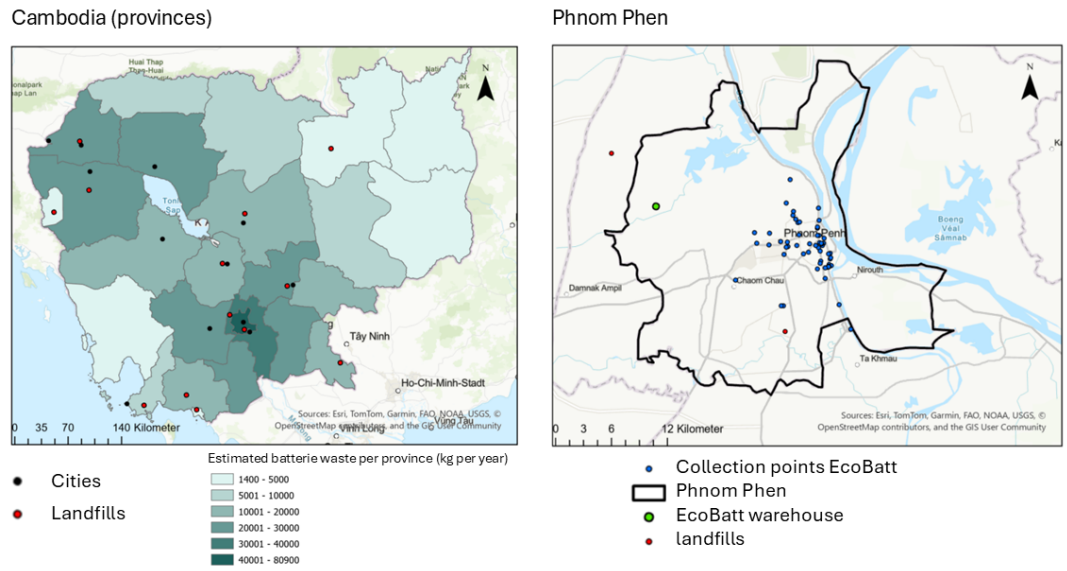


Figure 13: Visualisation of Battery Waste per province and ECOBATT Energy Cambodia collection points in Phnom Penh.

The battery waste concentration correlates positively with the inhabitants per km² and is the highest in areas around the main capital Phnom Penh as well as the region around Sieam Reap and Battambang in the Northwest of the country. Very low concentration of battery waste can be seen in the northeast and the southwest of the country where a more rural living structure is prevalent.
Regarding the collection points we see a high concentration along the city center of Phnom Penh, while the outskirts of the city have very low concentration of collection points. Statistically one collection point in the Phnom Penh area serves 9,000 citizens. Just for comparison in Germany the density of collection points is 417 inhabitants per collection point (200.000 boxes on 83,500,000 inhabitants) (Batterie-zurück, 2022). As an indicative benchmark, the collection-point density in Germany is substantially higher. While the German system is not directly transferable to Cambodia, the comparison illustrates the potential scale of expansion required to achieve dense and convenient consumer access.

The following figure shows a collection point operated by ECOBATT Energy Cambodia on the left. As there are no treatment options for collected waste batteries in Cambodia, the collected batteries are stored in 160-litre plastic barrels. The collection system collects approximately 2 Mg of batteries per year and currently stores around 10 Mg (2025) of batteries as a mixed fraction in storage containers.



Figure 14: Current Collection Infrastructure by ECOBATT Energy Cambodia. **A**: Collection Points in Public Space; **B**: Battery Storage in Plastic Barrels and Containers as a Mixed Fraction.

Also worth mentioning is VERYWORDS Cambodia, a Korean company that is building a plant for the mechanical treatment of lithium-ion batteries (LIBs) in Cambodia (see Figure 15).



Figure 15: Plant for the pretreatment of LIB from the company VERYWORDS in Cambodia.

The aim is to process the company's own electric-scooter batteries at the end of their service life. VERYWORDS' pretreatment process involves shredding, sieving and sorting to produce high-quality secondary raw materials that can be exported to South Korea for further recycling. The plant could also be used to handle LIBs from other sources, such as dismantled WEEE, rather than solely those from the company's own scooters. This would increase battery waste management safety and offer alternative revenue streams for VERYWORDS Cambodia.

4 BATTPRO Project Approach

As previously shown in the chapter “Introduction and Objectives”, the project was aligned along certain work packages. The results of the work packages are displayed in the following four chapters spreading from a battery waste projection that builds on the baseline assessment, to different process scenario developments and results, to an economic model for down streaming of batteries and planning of a coherent EPR system that aligns with local conditions.

4.1 Battery Waste Projection

Cambodia imported an average of 1,734 Mg of batteries and accumulators per year (5,202 Mg in total) between 2022 and 2024 that were not built into products (UN, 2025). This figure is based on UN Comtrade data and represents the average for the years 2022 to 2024. A detailed overview of the HS codes analysed in the UN Comtrade database is provided in the Annex (UN, 2025). It is not realistic to assume that all imported batteries are placed directly on the Cambodian consumer market after import. Some batteries may be integrated into battery-powered devices during production processes in Cambodia and subsequently re-exported. Others may be used in the military sector, hospitals or other professional applications without entering private households directly.
Nevertheless, two conclusions can be drawn with confidence: the imported battery mass crosses Cambodia’s borders and enters the country’s consumption system, and there is a continuous demand for batteries in Cambodia. In this sense, the Cambodian battery market can be understood as a black box: batteries enter the system, but their subsequent use, storage, transfer or disposal pathways are largely unknown.
Due to these uncertainties, the following projections focus only on replaceable device batteries. Imported electrical and electronic equipment (EEE) was excluded because it is unclear which products contain batteries and which do not. In addition, batteries embedded in EEE should be managed through a separate take-back system for waste electrical and electronic equipment (WEEE). Such devices are typically collected separately from loose replaceable batteries and sent to dismantling sites, where embedded batteries are extracted.
After safe extraction, batteries from WEEE may be transferred to the battery processing steps in a sorting facility. However, as they belong to a different waste stream and require a separate collection and dismantling logic, they were excluded from the following scenario development and EPR fee modulation process.

Current projections suggest that the amount of portable batteries could grow by approximately 5.5 % per year (Consulting and Insights, 2024; Data Horizon Research, 2025; Mordor Intelligence, 2026). For modelling purposes, an annual growth rate of 5.5 % was applied to the replaceable portable battery import mass. Accordingly, Figure 16 shows the possible development of battery import mass over the next ten years.

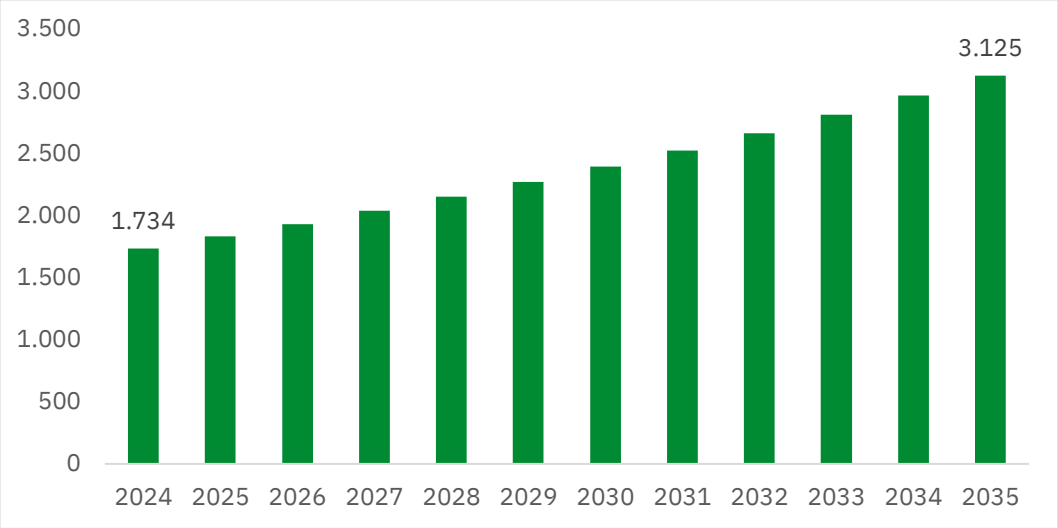


Figure 16: Imported Battery Projection 2024 – 2035.

As a result, the average imported amount of portable and replaceable batteries will increase to 3,125 Mg per year in 2035. That's an 80 % increase taking into account the current imported mass of batteries as a base value. Accordingly, more and more batteries will become waste after the use phase and enter the waste management system.

In order to develop a sound understanding of the necessary expansion of the collection infrastructure, the available data were visualized in a map using ArcGIS. Figure 17 shows Cambodia divided into provinces. The colour representation reflects the battery mass generated in households, with darker shades of blue indicating higher annual waste volumes. It should be noted that the area size of the provinces is not included in the presentation, but the absolute quantities correlate strongly with the respective number of households. The map shows particularly high volumes of waste in the Phnom Penh area and in the northern part of the country, especially in the provinces around the cities of Battambang, Siem Reap, Poipet and Sisophon. In addition, the twelve largest cities and the officially designated landfills are noted. However, the technical condition of these landfills is largely unknown, and it is unclear whether all facilities have a multi-barrier system. Larger landfills are typically located near urban centres.

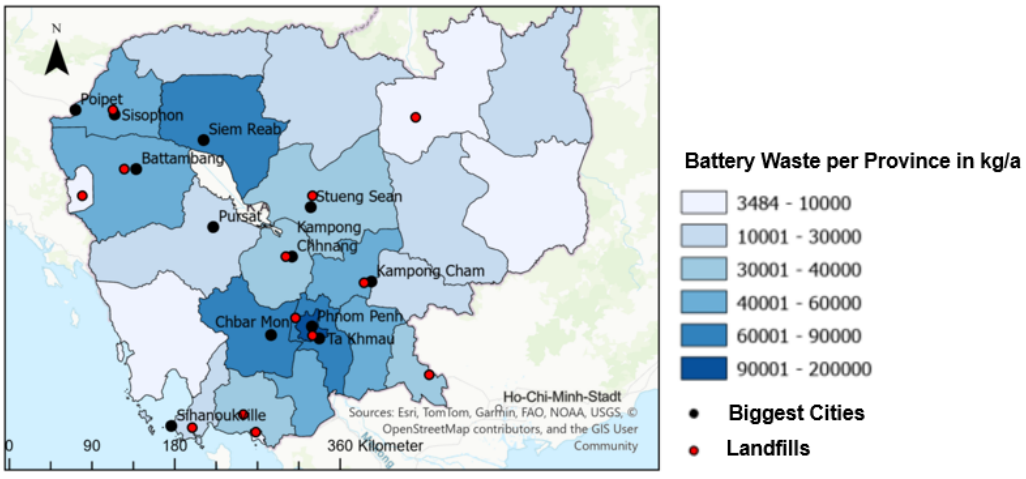


Figure 17: Overview of battery waste per Province in 2035.

4.2 Process Scenarios

Based on analyses carried out during the project, three scenarios were developed for how battery waste management in Cambodia could evolve over a ten-year horizon. The selected scenarios were a baseline scenario in which the current situation continues, a realistic scenario with improved collection infrastructure, and an optimistic best-case scenario including a full-scope take-back and recycling system.

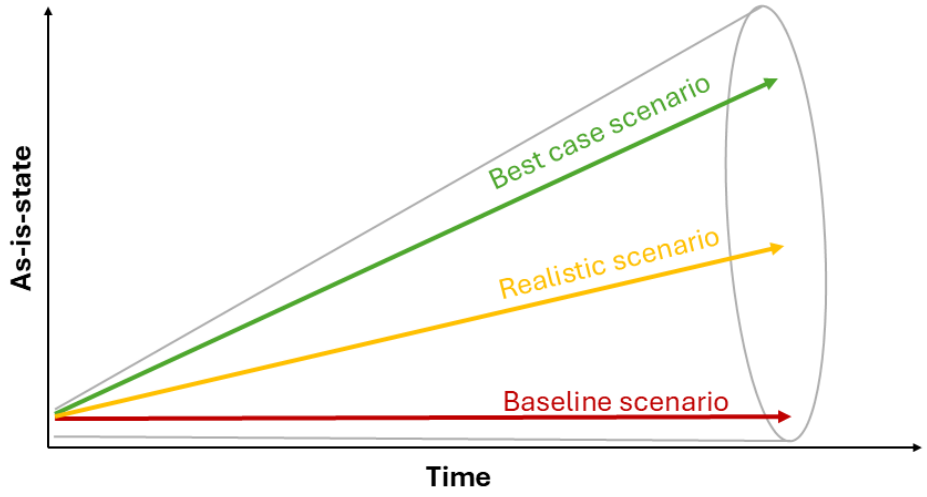


Figure 18: Scenario Funnel for Scenario Development. (acc. to Reibnitz, 1992)

The specific processes and collection-rate parameters for each scenario are shown in the following figure. Each process in each scenario was discussed in a stakeholder workshop and parameterised accordingly.

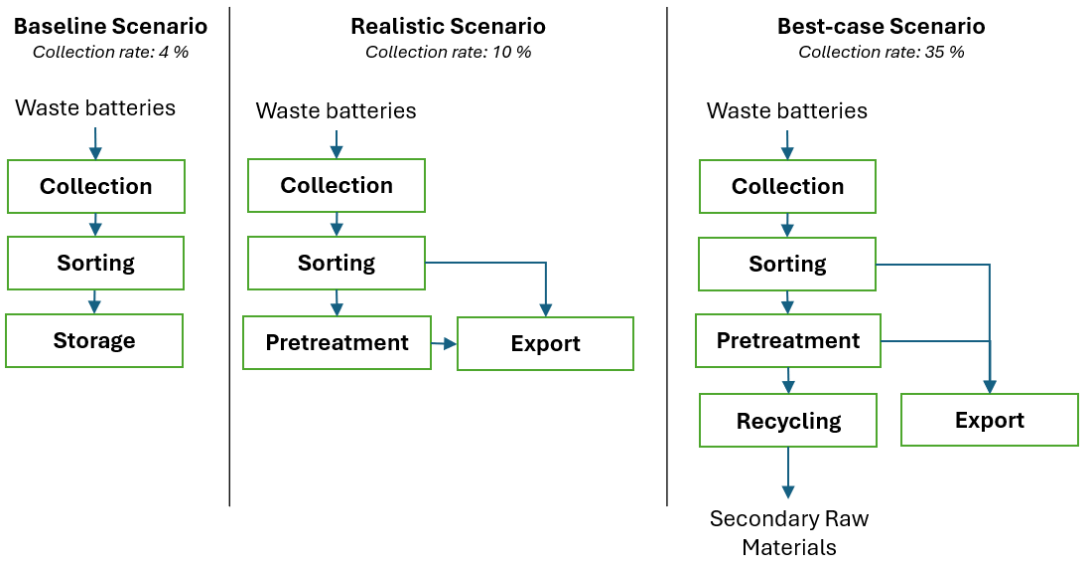


Figure 19: Overview on chosen collection rates and identified processes per downstream scenario.

Each scenario was modelled in an Excel tool that is showing the outcomes for different scenario parameters. The tool is adaptable to other market situations and their respective parameters and circumstances worldwide. The following parameters are adaptable:

1. Batteries put on the market
2. Battery market composition
3. Collection rate
4. Transfer coefficient between and in the different processes
5. Specific calculation parameters like energy demand per plant component, capacity utilisation etc.

The results of the scenario modelling are displayed in the following three figures showing different material flow diagrams (MFD).

Scenario 1 – Baseline Scenario

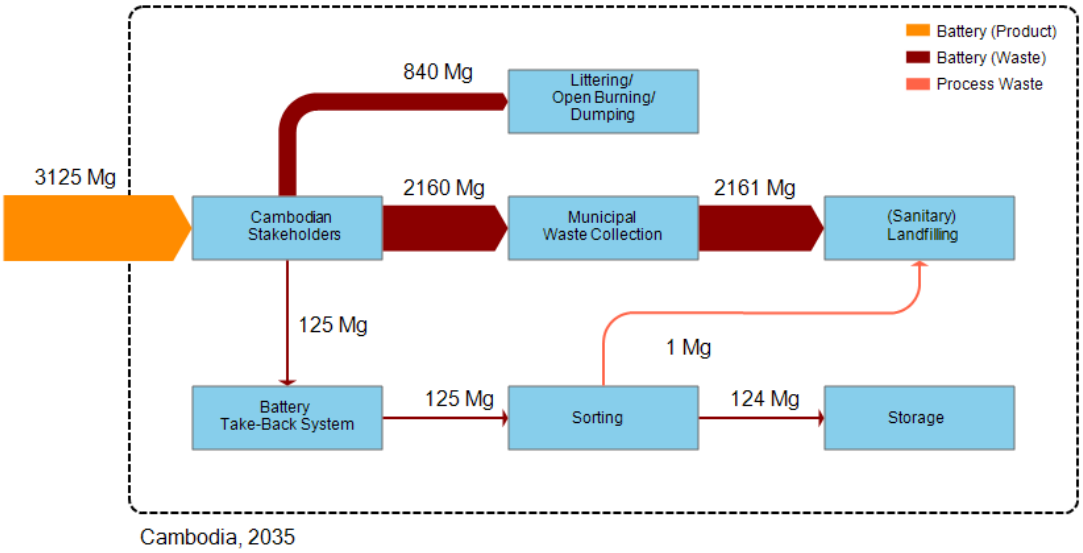


Figure 20: Material Flow Diagram for Baseline Scenario, Cambodia 2035.

The MFD for the baseline scenario shows an increase in the mass of collected batteries from the current level of 2 Mg per year to 125 Mg per year. This depends on the assumption that the annual collection rate of 3.5 % applies to the total amount of batteries imported into the country. As there is not yet a register in which producers can report batteries placed on the market (POM), the only practical assumption is that most imported batteries are consumed in Cambodia and subsequently become waste within Cambodian territory. The final disposal route in this scenario is storage, where 124 Mg per year ends up as waste. Assuming an average filled storage-barrel weight of 180 kg, this equals 689 barrels per year.

Scenario 2 – Realistic Scenario

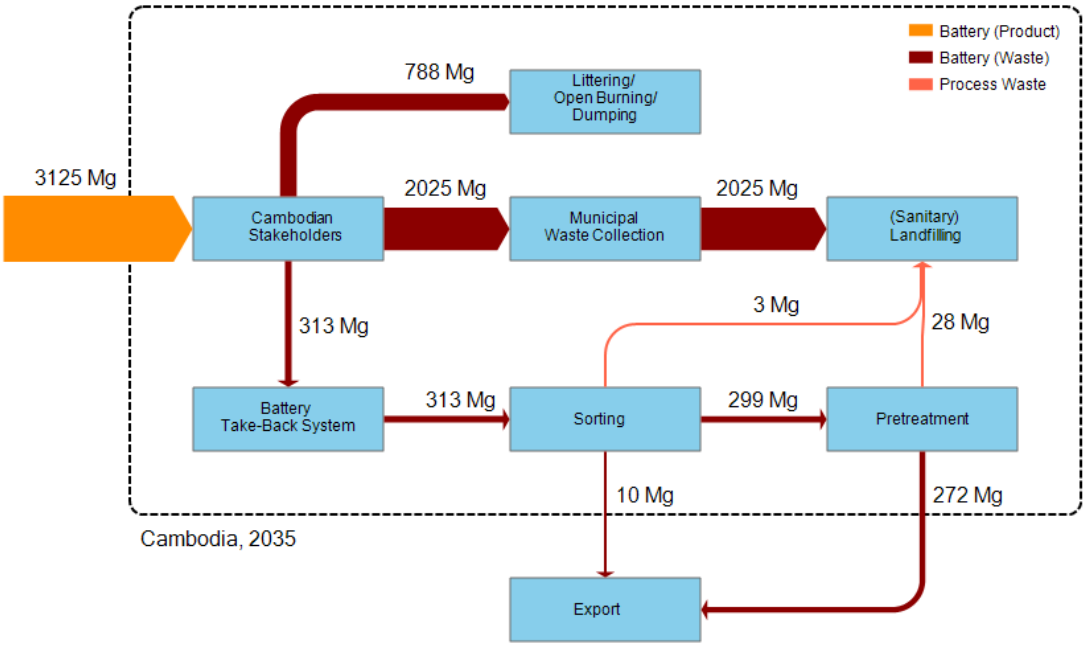


Figure 21: Material Flow Diagram for Realistic Scenario, Cambodia 2035.

In the realistic scenario, the collection rate increases to 10 %, and the mass of collected batteries rises from 125 Mg to 313 Mg per year. Assuming that household disposal behaviour does not change in terms of the distribution between littering and municipal solid waste disposal, both waste streams are reduced by 6 % compared with the baseline scenario. With regular sorting and pretreatment processes in place, a total of 282 Mg is exported each year. Sorting and pretreatment generate 31 Mg of waste for landfilling or co-processing.

Scenario 3 – Best-case Scenario

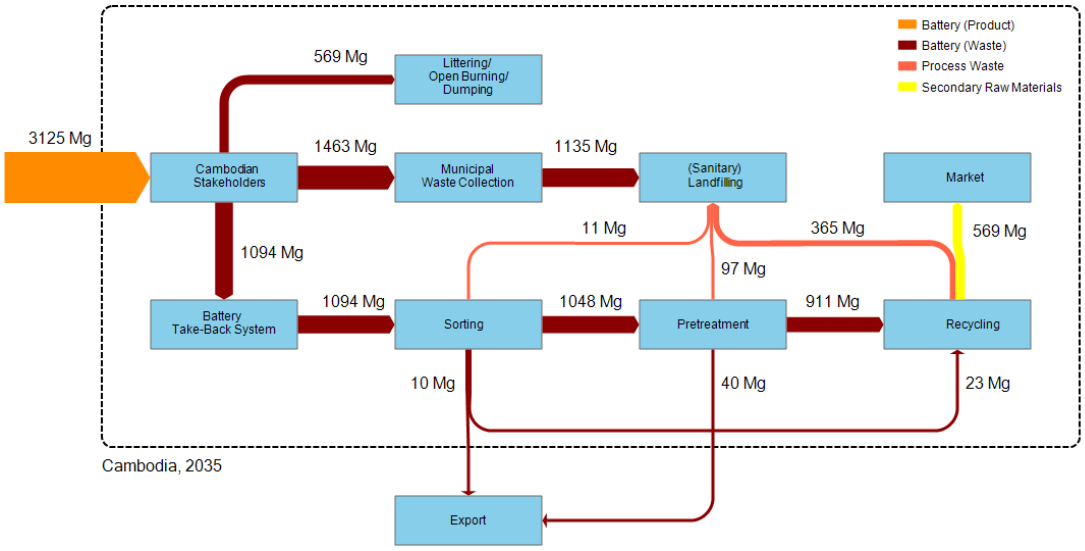


Figure 22: Material Flow Diagram for Best-case Scenario, Cambodia 2035.

In the best-case scenario, the collection rate increases to 35 %, resulting in 1,094 Mg of collected waste batteries per year. As Cambodia develops its own small-scale pyrometallurgical recycling infrastructure in this scenario, the quantity of exported materials decreases to 50 Mg per year, while the waste stream sent for recycling increases to 911 Mg per year. Taking slag production and process losses into account, 569 Mg of secondary raw materials can be produced through pyrometallurgical recycling. Whether these materials are exported or used within the Cambodian market remains an open question. In total, 473 Mg of waste for landfilling or co-processing is generated during sorting, pretreatment and recycling.

4.3 Economic Model

The economic model demonstrates that a very low per-battery import fee would be sufficient to finance the entire downstream system efficiently.

For each process identified in each scenario, economic parameters such as capital expenditure (CAPEX), operating expenditure (OPEX) and variable costs were assessed. For the "Export" and "Storage" processes, only OPEX and no CAPEX were estimated. In addition, the number of jobs that could be created along the downstream value chain for waste batteries was calculated, with each job generating purchasing power and tax revenue.

In a first step the authors identified for each process per scenario, relevant components. The researched plant components per process are displayed in the following table.

Table 1: Plant Components per Process Step.

Take-back & Collection	Sorting	Pretreatment	Recycling	PRO system operation
Collection Truck	Conveyor Belt	Battery shredder incl. fire suppression	Small smelting furnace	IT Infrastructure
Collection Boxes	Sorting Boxes	Vibratory Screen	Off-gas treatment system	Brand/Communication Setup
Pallets, trolleys and basic loading equipment	Scale	Magnetic + Eddy Current	Metal tapping & casting equipment	Team Setup
Safety Gear and PPT	Feed Hopper/Buffer	Dust Collection	Feed handling system	
Miscellaneous	Chairs/Work station	Conveyors, hoppers, control system	Cooling water system	
	Fire Safety Basics	Forklift		
	Extra lightning	Extra Safety Infrastructure		
	Miscellaneous			
	Automatic X-Ray Sorter			

In the annex you can find an overview of German companies delivering some of the identified equipment.

As a second step, investment costs and depreciation times for each plant component were estimated as well as OPEX costs per process including the following cost items:

- Personnel costs

- Maintenance costs
- Variable costs
- Overhead & administrative costs

The following assumptions were made when estimating the costs:

- Personnel costs per year were process and throughput dependent and differentiated between unskilled worker, skilled worker and lead worker.
- Maintenance costs per year were estimated to be 10 % of Investment costs for plant components.
- Overhead & administrative costs per year were estimated to be 20 % of OPEX excluding Overhead and administration.
- Income generated by process owners from sales of valuable materials and similar sources was assumed to contribute 80 % to process cost recovery, with the remaining 20 % of sales revenue retained by the companies.

The variable costs were split up in the main cost categories with slight differences between the different processes per year:

- Electricity and/or fuel costs
- Consumables and/or reagents costs
- Residue disposal costs
- Packaging costs
- Treatment/gate fees

The following table gives an overview of year one investment and installation costs per process per scenario.

Table 2: Overview Investment Costs Year 1 per Process and Scenario.

Process	Baseline	Realistic	Best-case
Take-back and Collection	39,000 USD	57,000 USD	120,000 USD
Sorting	23,000 USD	27,000 USD	372,000 USD
Pretreatment	- USD	451,000 USD	451,000 USD
Recycling	- USD	- USD	2,200,000 USD
EPR-Management	115,000 USD	115,000 USD	115,000 USD
Total Investment Costs	**177,000 USD**	**649,000 USD**	**3,255,000 USD**

Investment costs across the three scenarios increase almost linearly with the collection rate until a threshold is reached, after which it becomes more economical to switch from simple storage to pretreatment (USD 451,000 investment) and from semi-automatic sorting to a fully automatic X-ray sorter (USD 300,000 investment). In addition, implementing local pyrometallurgical recycling processes leads to high investment costs (USD 2.2 million).

The following table gives an overview of the estimated yearly OPEX in the three scenarios.

Table 3: Overview OPEX per process and Scenario.

Process	Baseline	Realistic	Best-case
Take-back and Collection	40,000 USD	83,000 USD	220,000 USD
Sorting	57,000 USD	133,000 USD	125,000 USD
Storage	66,000 USD	- USD	- USD
Export	- USD	80,000 USD	34,000 USD
Pretreatment	- USD	111,000 USD	239,000 USD
Recycling	- USD	- USD	559,000 USD
EPR-Management (non-profit)	56,000 USD	65,000 USD	96,000 USD
Total Scenario Costs	**219,000 USD**	**472,000 USD**	**1,273,000 USD**

Operational costs vary heavily between different scenarios, as the different processes have different levels of complexity. The higher the technical complexity in the process, the higher the operational costs. This can be seen best for the recycling and pretreatment costs which increase heavily from the realistic to the best-case scenario due to high costs for maintenance, electricity and variable costs. Export costs decrease between realistic and best-case scenario as more waste fractions can be treated in Cambodia and don't need export anymore.

The following table provides an overview of the estimated annual system costs in the three scenarios. The annual net system costs include depreciated investment costs and operating costs, but deduct the assumed contribution of material revenues to process cost recovery. They therefore represent the remaining annual financing requirement of the system before profit margins, rather than gross operating costs.

Table 4: Overview net annual system costs after depreciation and material revenue contribution.

Process	Baseline	Realistic	Best-case
Take-back and Collection	46,000 USD	91,000 USD	235,000 USD
Sorting	59,000 USD	136,000 USD	159,000 USD
Storage	67,000 USD	- USD	- USD
Export	- USD	80,000 USD	34,000 USD
Pre-Treatment	- USD	97,000 USD	68,000 USD
Recycling	- USD	- USD	155,000 USD
EPR Management (non-profit)	79,000 USD	88,000 USD	120,000 USD
Total Scenario Costs	**251,000 USD**	**492,000 USD**	**771,000 USD**

Job creation

Besides value creation through a circular economy process and keeping secondary raw materials in the loop, downstream management of waste batteries creates jobs. The following table gives an overview of the jobs created by each process per scenario.

Table 5: Job creation per process and scenario.

Process	Baseline	Realistic	Best-case
Take-back and Collection	3	5,75	15,5
Sorting	8	19	17
Storage	0	0	0
Export		2	2
Pretreatment		2,5	5
Recycling			8
EPR-Management (non-profit)	4	4,5	6
Total Jobs created	**15**	**33,75**	**57,5**

As system complexity and collection rates increase, more jobs are created. Employment effects are expressed as full-time equivalents (FTE). The model estimates an increase from 15 FTE in the baseline scenario to 33.75 FTE in the realistic scenario and 57.5 FTE in the best-case scenario.

It should be noted, however, that beyond a certain collection volume, investing in a fully automatic X-ray sorter becomes more cost-effective than continuously increasing manual sorting staff. For this reason, the number of sorting personnel decreases by two in the best-case scenario, as part of the sorting process is automated. A fully automatic X-ray sorter can provide the sorting capacity of up to 43 full-time equivalents per year when operated in two shifts per day.

4.4 EPR-Scenario

EPR Fee estimation

The system costs displayed in The following table provides an overview of the estimated annual system costs in the three scenarios. The annual net system costs include depreciated investment costs and operating costs, but deduct the assumed contribution of material revenues to process cost recovery. They therefore represent the remaining annual financing requirement of the system before profit margins, rather than gross operating costs.

Table 4 are based on investment costs being depreciated over certain time horizons, OPEX costs and 80 % revenue of sales of valuable materials being used to cover process costs in

a company. In this estimate, no profit margin was included. Therefore, the following chart provides an overview of system costs per scenario including a 20 % profit margin per scenario and a specific cost per battery to finance the downstream scenario.

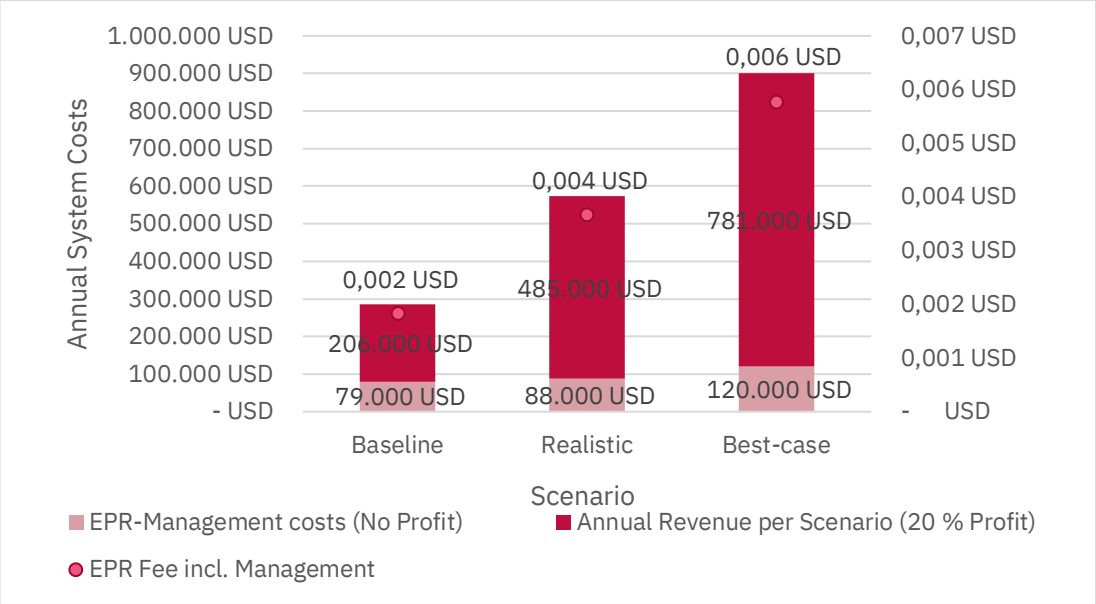


Figure 23: Overview of system costs and specific EPR-fee per battery.

The non-profit costs for managing the EPR system through a producer responsibility organisation increase only moderately from 79,000 USD to 88,000 USD. They are only weakly dependent on the collection rate, as this mainly affects variable costs in the model. In the best-case scenario, annual system management costs rise to 120,000 USD. Across the scenarios, total system costs increase steadily from 206,000 USD in the baseline scenario to 485,000 USD in the realistic scenario and 781,000 USD in the best-case scenario.

The EPR fee was calculated by dividing the total annual financing requirement by the estimated number of batteries placed on the market. The financing requirement consists of the scenario-specific downstream system costs, including the assumed profit margin, plus the non-profit costs of PRO system management. Based on annual system costs, an imported battery mass of 3,125 Mg per year and an average battery weight of 20 g, the required EPR fee would be:

- 0.002 USD per battery (baseline scenario);
- 0.004 USD (realistic);
- 0.006 USD (best-case).

This corresponds to 0.43 % of the average battery price in the baseline scenario, 0.87 % in the realistic scenario and 1.37 % in the best-case scenario.

EPR-System

How a possible EPR scenario could look on an organisational level shows Figure 24. As there are many other possibilities for how an effective EPR system could be set up, the scheme therefore only has the purpose of showing one possibility and for explaining how the different stakeholders work together in the system.

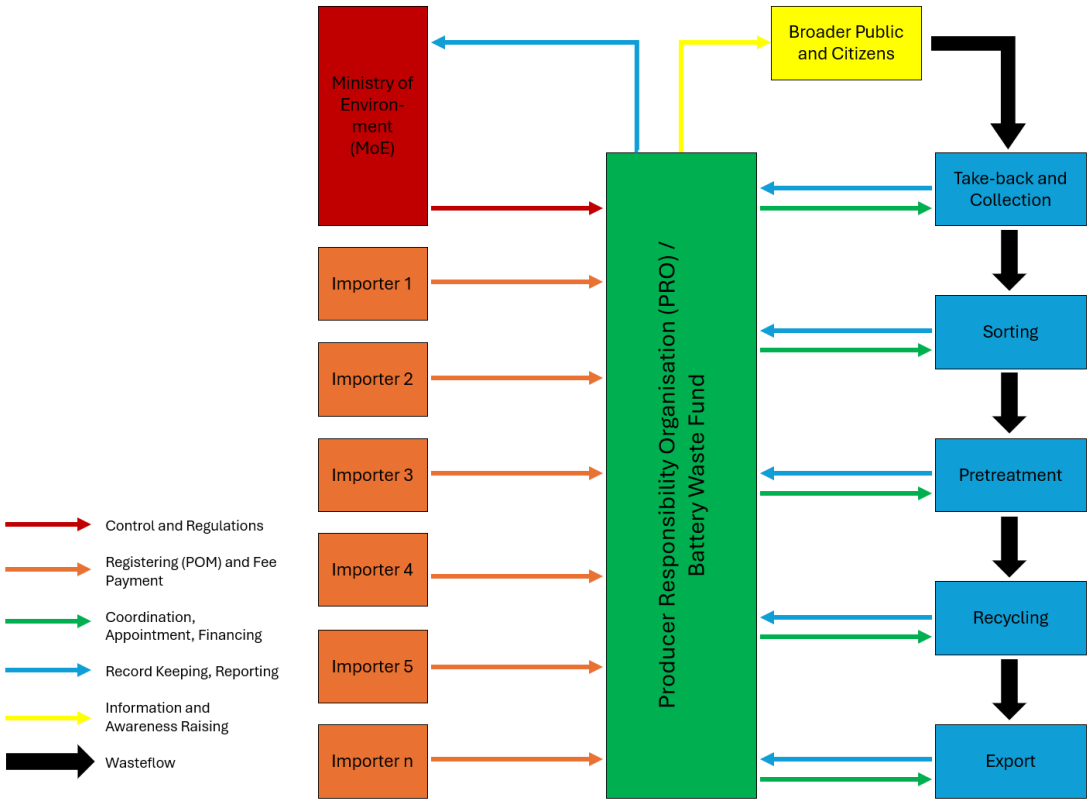


Figure 24: Possible EPR-Scenario for Cambodia with different stakeholders and flow types.

In this scenario, the Ministry of Environment (MoE) would designate a Producer Responsibility Organisation (PRO) or Battery Waste Fund and give it the legal mandate to manage the battery lifecycle in Cambodia. The PRO would report annually to the MoE on battery collection and treatment volumes as well as financial performance. Battery importers would be required to register with the PRO and report monthly on the quantities of batteries imported and their destination. The EPR regulation could extend these obligations to distributors and other entities placing batteries on the market. The MoE could also fine non-compliant actors or prohibit them from selling batteries in Cambodia. Based on reported market volumes, the PRO would tender services across the downstream battery value chain. Qualified service providers could bid for these contracts, set their own prices, document the batteries processed, and report the results to the PRO. The PRO would also fund public awareness campaigns on correct battery disposal and associated risks. It would pay contracted service providers and recover the costs through fees charged to importers, distributors, and other obligated actors.

5 Roadmap (short-, medium-, and long-term)

To establish sustainable EPR structures for the take-back and recovery of portable batteries, a roadmap is presented below. For the implementation, various areas are addressed in which specific measures are proposed. By means of the described recommendations for action, different milestones can be achieved in the short-, medium- and long-term period, through which the implementation of a sustainable battery take-back system is enabled.

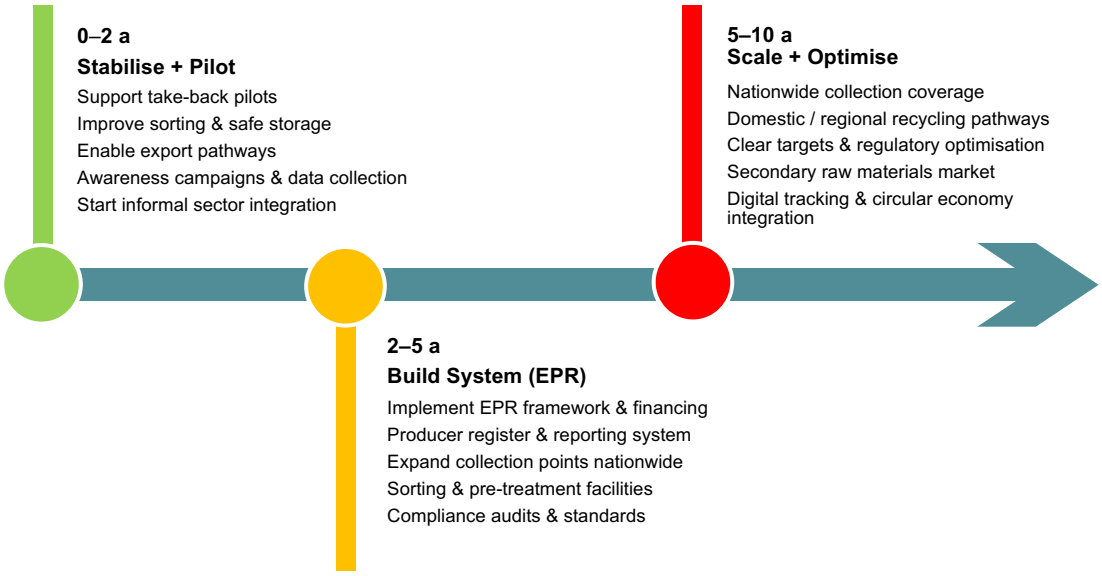


Figure 25: Compact roadmap overview.

5.1 Short Term Roadmap – Stabilise and Pilot

In the short-term development phase, the creation of basic prerequisites for the later introduction of an EPR regulation for portable batteries is required. This includes the early definition of roles and responsibilities between the Ministry of Environment, the private sector and other participating actors, the establishment of simple reporting structures and classification standards as well as initial training measures. At the same time, the expansion of first take-back points with a broad catchment area, such as schools, public buildings or large retail outlets, as well as the development of standardised and, where necessary, fire-safe collection containers is required. In addition, safe interim storage facilities should be identified as a transitional solution, the logistics for collection, transport and export should be prepared and the cost structures of collection and recovery should be assessed. In order to prepare the implementation socially and institutionally, the establishment of a coordinated stakeholder platform as well as first information and awareness-raising campaigns is expedient. In addition, it should be examined which regional or international recovery and

recycling partners are available in the short term, so that the collected batteries can already be transferred to proper treatment in the initial phase.

Table 6: Overview of the categories of action and short-term measures.

Category	Measures
Governance & Regulatory Framework	Clarify roles and responsibilities between Stakeholders (Ministry of environment, municipalities, private sector) Establish temporary permitting/licensing rules for collectors and aggregators Develop interim technical guidelines for: ● safe storage ● transport ● handling of batteries
Institutional Capacity, Data & Compliance	Start baseline data collection & reporting requirements Improve sorting quality with employee training and basic classification standards
Collection & Take-back	Support existing collectors, where feasible incl. informal sector Provide standardised collection containers and taking fire safety into account Pilot high-yield collection channels, for example: ● retail take-back ● schools / public buildings Map and support informal collectors integration without displacement
Logistics & Infrastructure	Identify and secure interim storage hubs Optimise export logistics for sorted fractions Ensure safe storage and compliant export pathways
Financing & Market Development	Provide pilot-based funding and formal support for existing take-back schemes Provide public co-funding for pilots Explore cost structure for collection & export Start of concept development for future EPR financing
Communication & Stakeholder Engagement	Start of a working group led by the from Ministry of Environment to implement a stakeholder coordination platform Increase public awareness campaigns with following target groups: ● retailers ● households ● schools Develop simple behavioural messages, for example “Do not dispose in household waste” Engage large retailers/importers as communication multipliers
Recycling, Circular Economy & Innovation	Explore recycling possibilities for sorted batteries

	Identify reliable regional and international downstream partners

5.2 Mid Term Roadmap – Build EPR System

In the mid-term development phase, the further development of the prepared structures into a more binding and operationally viable EPR system is required. This includes the definition of the future system design, including the configuration of possible PRO structures, binding obligations for producers, importers and entities placing batteries on the market, as well as initial collection and recovery targets. At the same time, a national product register, uniform reporting structures, clear requirements for documentation as well as audit and monitoring mechanisms need to be established to improve the data basis, traceability and control of the system. For operational implementation, the expansion of take-back points, including solutions for rural areas, is required, as is the introduction of a legal take-back obligation at points of sale. In addition, a nationwide logistics network for the safe transport of end-of-life portable batteries should be established and secured by further developed safety standards, particularly in fire protection and hazardous substance handling. For financial stabilisation, clear financing flows, contributions from the obligated actors as well as a transparent cost allocation for collection, transport, sorting, storage and, where applicable, export need to be defined. Furthermore, communication should be more strongly institutionalised, supplemented by recurring information formats and target-group-specific materials, and supported through the continuous involvement of schools, municipalities, retail and importers. Finally, around recycling and circular economy, the development of national sorting and pre-treatment structures should be pursued in order to improve the quality of material flows, reduce safety risks and create the basis for later material recovery.

Table 7: Overview of the categories of action and mid-term measures

Category	Measures
Governance & Regulatory Framework	Decision about future EPR-System design: ● non-profit vs. for-profit ● state vs. producer-led ● number of PROs Development and adoption of EPR legislation Definition of clear obligations for producers and importers Definition of initial and future collection and recycling targets Definition of battery categories covered Addressing built-in / non-replaceable batteries in accordance with the WEEE framework Establish enforcement mechanisms, such as inspections or penalties

Institutional Capacity, Data & Compliance	Development and implementation of: • national producer register • reporting system (placed on market & collected volumes) Development of PRO setup and governance model Establishment of a central coordination unit involving the Ministry of Environment Training and development of audit schemes Introduction of an audit and monitoring system Definition of minimum downstream standards e.g.: • WEEELABEX • ISO • Basel Convention compliance Creation of approved recycler and exporter list Introduction of documentation chain to develop a traceability system
Collection & Take-back	Introduction of mandatory take-back requirements for distributors and retailers Increase number of collection points and introduction of municipal collection points Development of rural collection solutions, like mobile collection or periodic systems
Logistics & Infrastructure	Setting up a national logistic network Improve safety standards to cover fire protection and the handling of hazardous materials
Financing & Market Development	Setting up EPR financing flows Definition of eco-fees and cost allocation model Introduction of an optional eco-modulation
Communication & Stakeholder Engagement	Expand the stakeholder coordination platform to include stakeholders of rural regions Optimise public awareness campaigns to increase public outreach and extend coverage to rural areas Promote continuous stakeholder engagement and knowledge exchange
Recycling, Circular Economy & Innovation	Establishment of sorting and pre-treatment facilities

5.3 Long Term Roadmap – Scale and Optimise

In the long-term development phase, the permanent consolidation and further development of the EPR system for portable batteries is the main focus. This includes the extension of the

regulatory framework to national collection and recycling quotas as well as a continuous adaptation of the legal framework to international requirements. In addition, the institutional structures created should be further strengthened through digital tracking systems, regular material flow monitoring and improved data analysis in order to ensure cost efficiency, transparency and control of the system in the long term. For operational implementation, the establishment of a nationwide take-back network is required, covering both urban and rural areas and being easily accessible for consumers. Likewise, logistics and infrastructure development should be geared towards ensuring safe, stable and permanently viable transport, storage and treatment structures. For financial safeguarding, self-sustaining financing through the PRO should be pursued, including a regular review of the fee structure and stronger integration of secondary raw material markets. Furthermore, permanent communication and participation formats are required in order to support public awareness, acceptance and the further development of battery collection. In the area of recycling, circular economy and innovation, battery take-back should be integrated into an overarching national circular economy strategy, including the assessment of local or regional recycling and pre-treatment capacities, possible ASEAN hub solutions as well as safety-related second-life and reuse approaches.

Table 8: Overview of the categories of action and long-term measures

Category	Measures
Governance & Regulatory Framework	Definition of clear national targets for collection rate and recycling efficiency Continuously improvement of regulatory framework Alignment with regional and international standards
Institutional Capacity, Data & Compliance	Implementation of digital tracking systems Improvement of efficiency and cost optimisation Introduction of advanced data systems to monitor material flows
Collection & Take-back	Achievement of nationwide collection coverage with high accessibility in urban and rural regions
Logistics & Infrastructure	Expand logistics infrastructure to achieve nationwide coverage, including rural and remote regions
Financing & Market Development	Development of secondary raw material markets Encourage public-private partnerships
Communication & Stakeholder Engagement	Implement communication measures as a nationwide public awareness campaign
Recycling, Circular Economy & Innovation	Introduction of eco-design incentives (repairability, removability) Establishment of local recycling facilities, if economic feasibility exists Development of semi-industrial pretreatment and export or full recycling pathways Evaluation of regional hub solutions with cooperations on ASEAN-level Promotion of battery reuse and second-life applications

	Integration of battery management into broader circular economy strategy

6 Conclusion and Outlook

BATTPRO was implemented over two years and developed a staged roadmap for improving portable-battery collection and downstream management in Cambodia. Alongside the technical assessment, the project engaged stakeholders from government, business, waste management and development cooperation, creating a network that can support future implementation. A central finding was the limited availability and reliability of market and waste-flow data. UN Comtrade data are affected by incomplete reporting, broad residual categories and limited opportunities for verification, while the bottom-up household assessment was based on a limited, non-representative sample and did not systematically differentiate by income, location or urbanisation. Cambodia's portable-battery flows should therefore not be described as entirely unknown, but as insufficiently transparent after batteries enter the country. The quantitative results in this report are model-based estimates that are suitable for identifying priorities, comparing scenarios and informing a staged roadmap. They are not sufficiently robust to determine final legal targets, infrastructure capacities or binding EPR fees without further data collection and validation. A producer and importer register would improve data on batteries placed on the market. On the output side, representative household surveys, municipal waste-composition studies and documented collection and treatment data would provide a stronger basis for estimating disposal pathways, public awareness and regional differences. These findings could then inform targeted communication and capacity-building measures, provided that accessible and safe collection options are available.

Despite these uncertainties, several conclusions are robust across the evidence reviewed: formal collection currently captures only a small share of portable-battery waste; safe downstream options remain limited; storage without a secured treatment route is not a sustainable long-term solution; and a phased system combining reporting, accessible collection, safe logistics and reliable downstream treatment is preferable to immediate investment in a complex domestic recycling system.

Successful implementation of the roadmap requires coordinated action by government, obligated companies, collection and treatment operators, municipalities, development partners and existing informal-sector actors. Five factors are decisive: a clear legal mandate with assigned roles and enforcement powers; early and continued participation by existing stakeholders; institutional capacity to register obligated actors, procure services and verify performance; reliable data for target-setting and monitoring; and predictable financing for collection, transport, storage, treatment, communication and administration. These elements should be developed in sequence, beginning with governance, registration and pilot operations before binding targets and more capital-intensive infrastructure are introduced.

A continuous communication and capacity-building programme is also required. Public communication should explain where batteries can be returned and why they must not enter household waste, while targeted training should equip authorities, importers, retailers, collectors, transporters and facility operators to fulfil their reporting, handling and safety responsibilities. Communication effectiveness should be monitored through indicators such as awareness, collection-point use and contamination rates.

The immediate next step should be a time-bound pilot phase with measurable milestones: designate a lead authority and coordination platform; establish interim registration and reporting for major importers; validate baseline data through representative surveys and

waste-composition studies; expand collection through selected retail, school and public-sector sites; secure compliant storage, transport and downstream treatment routes; and review the pilot after one full reporting cycle before setting binding national targets or final EPR fees.

Future investment decisions should follow verified throughput and cost thresholds rather than the ambition to maximise domestic treatment. In the near term, sorting, safe storage, pretreatment and export to qualified regional recyclers may offer a lower-risk pathway. Domestic recycling should be reconsidered only when stable collection volumes, composition data, environmental permitting, occupational-safety controls, reliable energy and residue-management arrangements, and viable markets for recovered materials can be demonstrated.

The EPR fee estimates should therefore be treated as indicative financing benchmarks rather than final tariffs. Before legal adoption, the fee model should be recalibrated using verified placed-on-market volumes, achieved collection rates, tendered service prices, transport and export costs, material revenues and administrative costs. Thereafter, fees and targets should be reviewed periodically so that the system can respond to market growth, inflation, technology changes and actual collection performance.

The transition should also recognise the role of informal collectors and repair actors. Registration, training, protective equipment, fair contracting and access to formal handover points can improve safety and traceability without abruptly displacing existing livelihoods. Any integration model should be tested through pilots and evaluated for collection performance, income effects and compliance with handling requirements.

The roadmap provides a phased basis for building an effective and sustainable portable-battery take-back system in Cambodia. Its value lies not in prescribing a fixed end-state, but in sequencing practical measures, testing them through pilots and adjusting targets, fees and infrastructure as better data become available. If implementation combines clear governance, reliable financing, accessible collection, safe downstream treatment and transparent monitoring, the system can reduce environmental and fire risks while supporting Cambodia’s broader transition towards a circular economy.

7 Annex

7.1 HS Codes Researched

HS Code	Description
8506	Primary cells and primary batteries; parts thereof
8506.10	Manganese dioxide primary cells and batteries
8506.30	Mercuric oxide primary cells and batteries
8506.40	Silver oxide primary cells and batteries
8506.50	Lithium primary cells and batteries
8506.60	Air-zinc primary cells and batteries
8506.80	Other primary cells and primary batteries
8507	Electric storage batteries, including separators therefor, whether or not rectangular, including square; parts thereof
8507.30	Nickel-cadmium storage batteries
8507.50	Nickel-metal hydride batteries
8507.60	Lithium-ion batteries
8507.80	Other storage batteries

7.2 List of Plant Components from German Companies

Table 1: List of plant components from German companies and suppliers.

Equipment	German Manufacturer / Shop	Location	ZIP-Code	Website
Collection Truck	ZOELLER-KIPPER	Mainz	55130	https://www.zoeller-kipper.de
Collection Boxes	SSI Schäfer	Neunkirchen	57290	https://www.ssi-schaefer.com
Collection Boxes	AUER Packaging	Amerang	83123	https://www.auer-packaging.com
Pallets/Trolleys	Jungheinrich	Hamburg	22047	https://www.jungheinrich.de
Safety Gear & PPE	UVEX	Fürth	90766	https://www.uvex-safety.com
Conveyor Belt	mf Fördertechnik	Zittau	02763	https://www.mf-foerdertechnik.de
Conveyor Belt	HaRo Fördertechnik	Rüthen	59602	https://www.haro-gruppe.de
Sorting Boxes	BITO Lagertechnik	Meisenheim	55590	https://www.bito.com
Scale	Minebea Intec	Hamburg	22305	https://www.minebea-intec.com
Feed Hopper/Buffer	AViTEQ	Hattersheim	65795	https://www.aviteq.com
Workstations	item Industrietechnik	Solingen	42699	https://www.item24.com
Fire Safety Basics	Minimax	Bad Oldesloe	23843	https://www.minimax.com
Lighting	Trilux	Arnsberg	59759	https://www.trilux.com
Automatic X-Ray Sorter	Sesotec	Schönberg	94513	https://www.sesotec.com
Battery Shredder	Erdwich	Kaufering	86916	https://www.erdwich.com

Vibratory Screen	Rhewum	Remscheid	42899	https://www.rhewum.com
Magnetic + Eddy Current	STEINERT	Köln	50933	https://www.steinert.de
Dust Collection	Keller Lufttechnik	Kirchheim unter Teck	73230	https://www.keller-lufttechnik.de
Forklift	STILL	Hamburg	22113	https://www.still.de
Small Smelting Furnace	OTTO Junker	Simmerath	52152	https://www.otto-junker.com
Off-gas Treatment	Keller Lufttechnik	Kirchheim unter Teck	73230	https://www.keller-lufttechnik.de
Metal Tapping & Casting	ABP Induction Systems	Dortmund	44379	https://www.abpinduction.com
Feed Handling System	AZO GmbH	Osterburken	74706	https://www.azo.com
Cooling Water System	technotrans	Sassenberg	48336	https://www.technotrans.de
IT Infrastructure	Bechtle	Neckarsulm	74172	https://www.bechtle.com
Brand/Communication	Serviceplan Group	München	80335	https://www.serviceplan.com

7.3 MFA System Description

Modelled System The material flow model shows the portable battery usage in Cambodian households. Lead-Acid Batteries are excluded from the system as they already have a relatively well-established recycling infrastructure and are recycled worldwide economically due to their lead content. The system distinguishes between replaceable batteries and non-replaceable batteries built into electrical and electronic equipment.

Model Type Due to data availability and baseline assessment of the situation, a static flow model was chosen.

System Boundary The system boundary is drawn over the Cambodian territory. A blackbox model was applied to display import and export flows of

(waste) batteries and (waste from) electrical and electronic equipment ((W)EEE) and a sub system model to display material flows between the use phase and the end-of-life phase of portable batteries in Cambodia.

Cut-off Criteria Material flows smaller than 1% of the total system throughput are neglected

Data collection approach Bottom up through electronic device usage estimation and top down through trade data and official statistical data. (See "**Fehler! Verweisquelle konnte nicht gefunden werden. Fehler! Verweisquelle konnte nicht gefunden werden.**")

Processes In total, nine different processes in Cambodia were identified. One import flow and one export flow. (See "**Fehler! Verweisquelle konnte nicht gefunden werden. Fehler! Verweisquelle konnte nicht gefunden werden.**")

Transfer Coefficients and Assumptions The transfer coefficients used to describe the material flow subsystems are described in chapter "**Fehler! Verweisquelle konnte nicht gefunden werden. Fehler! Verweisquelle konnte nicht gefunden werden.**".

7.4 Researched Electrical and Electronic Equipment

Table 9: Overview of devices, estimated battery chemistry, estimated battery type and replaceability of the battery.

Device	Estimated Battery Chemistry	Estimated Battery Type	Replaceable (y/n)
Portable fan	Lithium-Ion	Secondary Battery	No
Electric mosquito racket	Nickel-Metal Hydride	Secondary Battery	Yes
Clocks	Alkaline	Primary Battery	Yes
Watches	Silver Oxide	Primary Battery	Yes
Wireless earbuds / headphones	Lithium-Ion	Secondary Battery	No
TV remote controller	Alkaline	Primary Battery	Yes

AC remote controller	Alkaline	Primary Battery	Yes
Fan remote controller	Alkaline	Primary Battery	Yes
Flashlight	Alkaline	Primary Battery	Yes
Toy gadgets	Nickel-Metal Hydride	Primary Battery	Yes
Cameras	Nickel-Metal Hydride	Secondary Battery	No
Phones	Lithium-Ion	Secondary Battery	No
Microphones	Alkaline	Primary Battery	Yes
Speaker (portable)	Lithium-Ion	Secondary Battery	No
Powerbank	Lithium-Ion	Secondary Battery	No
Stove (battery ignition)	Alkaline	Primary Battery	Yes
Mouse	Alkaline	Primary Battery	Yes
Keyboard (wireless)	Alkaline	Primary Battery	Yes
Laptop	Lithium-Ion	Secondary Battery	No
Tablet	Lithium-Ion	Secondary Battery	No
Light remote	Alkaline	Primary Battery	Yes
Electric Tooth brush	Lithium-Ion	Secondary Battery	No
Hair trimmers	Lithium-Ion	Secondary Battery	No
Shavers	Lithium-Ion	Secondary Battery	No
Battery-Powered screw drivers	Lithium-Ion	Secondary Battery	Yes
Handheld vacuum cleaners	Lithium-Ion	Secondary Battery	No
Robotic Vacuum	Lithium-Ion	Secondary Battery	No

7.5 Researched Processes for MFA

Retail Flow of batteries being imported into Cambodia and then sold to households when they need to replace a battery in their device or when they buy an electronic device that contains a battery. It was

	specified that each battery that becomes waste is replaced by the household in the same year.
Household (Use-Phase)	Use phase of a battery during its life cycle. It can last from less than a year to many years depending on the battery type and the use intensity. In the model the use-phase time was estimated to be between 1 year and 10 years. A linear waste rate was chosen to model an equally distributed waste generation.
Littering / Open Burning / Dumping	Uncontrolled disposal of waste in public spaces or natural environments. Open burning releases toxic pollutants into the air, while dumping contributes to land and water contamination, harming ecosystems and public health. As its impossible to distinguish between them and no data is available about useage, they are combined in one process.
Municipal Waste Collection	Organised collection of household and commercial waste by local authorities or contracted service providers. This process is essential for maintaining urban cleanliness and directing waste to appropriate treatment or disposal facilities.
Informal Sector	Activities carried out by individuals or groups outside formal waste management systems, often involving collection, sorting, repair, resale and recycling of waste materials.
ECOBATT Energy Cambodia	A formal organisation focused on sustainable collection, transport and waste management in the battery sector.
Repair and Resale	Extending the life cycle of products by fixing and selling used items by the informal sector. This reduces waste generation and promotes circular economy practices by keeping materials in use longer.
(Sanitary) Landfilling	Disposal of waste in designated land areas. Alhough waste is collected by municipalities or designated companies it is not mandatory that the landfills used for disposal are sanitary landfills with a multibarrier system or dumpsites without barriers.
(Illegal) Export	(Unauthorised) shipment of waste materials, often to countries with weaker environmental regulations. This practice violates international

laws and can lead to severe environmental and health consequences in receiving regions.

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August 2026

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This report builds on data and analysis provided by Sevea Consulting Co., Ltd., Phnom Penh, commissioned under the BATTPRO project. We thank the Sevea team for their research, stakeholder engagement, and the preparation of the market study that supported the development of this report.

Citation Recommendation
Foundation GRS und ECOLOGICON GmbH (Hrsg. 2026), Professionalisation of Portable Battery Collection and EPR Structures in Cambodia. Findings and Recommendations from the BATTPRO Project. Hamburg