How battery life cycle influences the collection rate of battery collection schemes

Consolidated European report

January 2017

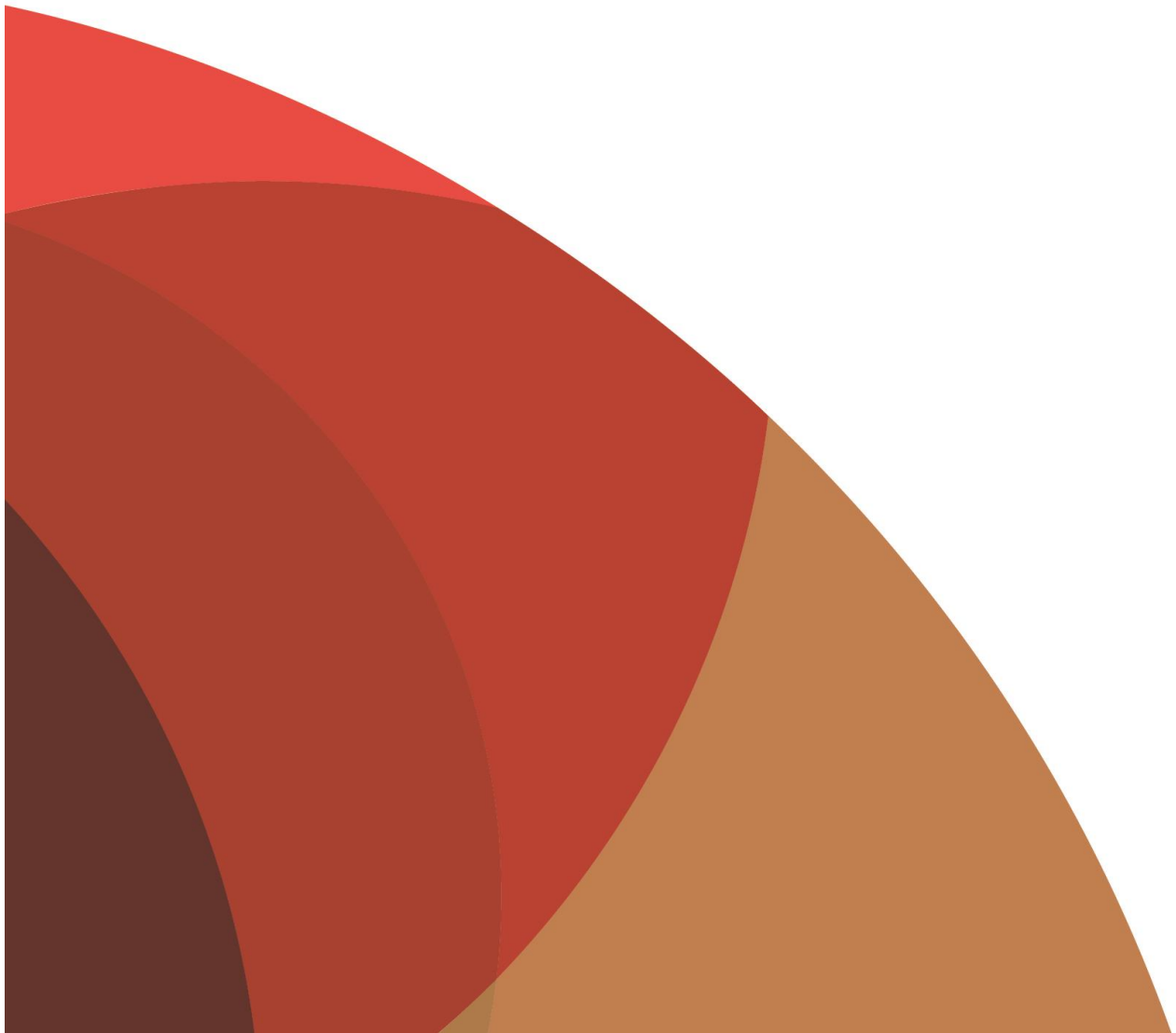


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Management summary

Eucobat is the European association of national collection schemes for batteries. They assure that all waste batteries are collected and recycled in an ecologically sound way, and contribute in this way to a better environment. Eucobat represents the interests of these national compliance organizations for batteries at the European level and provides for a platform for co-operation and exchange of information and best practices, in order to optimize the effectiveness of the operations of the member organizations. These member organizations are subject to the **European collection performance target** (EU target)[1].

In this light, a large **sampling study** was set up to evaluate the impact that the battery life cycle has on the amount of batteries that is discarded and, consequently, the collection performance. This study was performed for **six member organizations**: Bebat (Belgium), Corepile (France), GRS (Germany), Stibat (The Netherlands), Ecopilas (Spain) and SNRB (Romania). For each of these six member organizations, the results of the study are represented in individual reports and this report consolidates their findings, in order to extrapolate the results on the European level.

More specifically, this report aims at answering the following questions:

- Is the manner in which the EU target is calculated appropriate given the length of the battery life cycle?
- Is the EU target appropriate in case the weight of batteries put on market (POM) changes?

In order to answer these questions, a random sample of discarded batteries per chemical family was selected for all six member organizations and their "age" was recorded. In total, about **154,000 batteries**, of which 46,000 with a valid production date, were sampled in this manner so as to obtain representative samples for all chemical families of batteries at each of the six member organizations. In order to obtain results that are indicative for battery collection at the European level, a consolidated European sample was re-arranged from the member samples.

The next step consisted of calculating the average age of batteries in each chemical family. The results of this analysis show that the best possible estimation of the **average battery age**, when it is collected within the European market, is approximately **5.2 years**.

Next, the age distribution of each chemical family of batteries was computed. This is the percentage of batteries collected this year and produced 1 year ago, 2 years ago, 3 years

[1] EU target = 45% of the average over 3 years of the weight put on market.
Target to be achieved by 26/09/2016, cfr. Directive 2006/66/EC

ago… (see examples in Figure 1 and Figure 2). This information was combined with the data provided by the producers on the weight and groups of batteries they put on the market each year (POM), in order to compute an estimate of the weight of batteries being discarded each year.

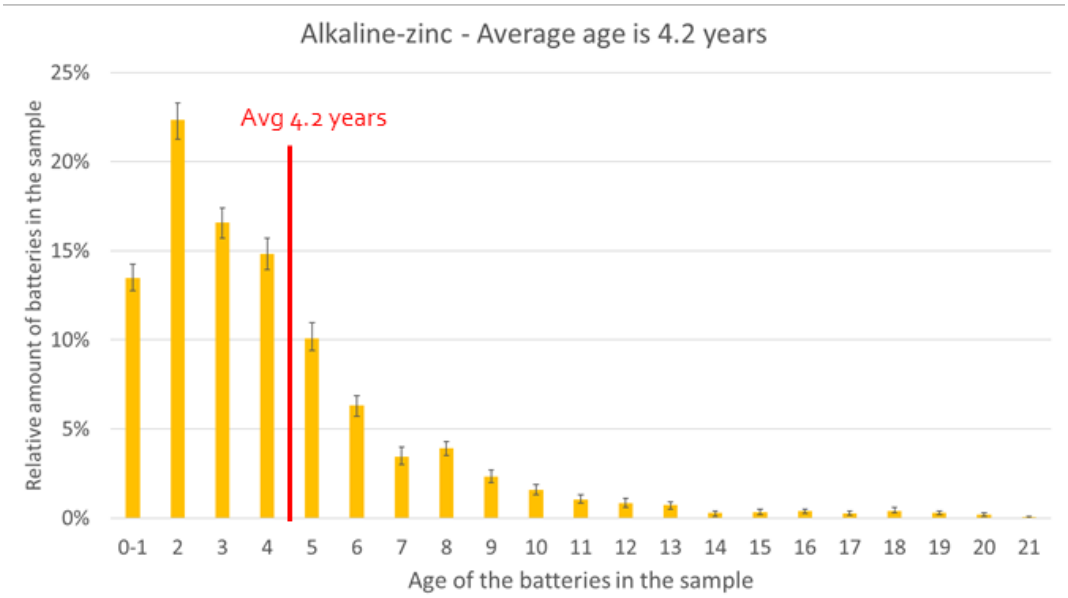


Figure 1: Age distribution of alkaline-zinc batteries.

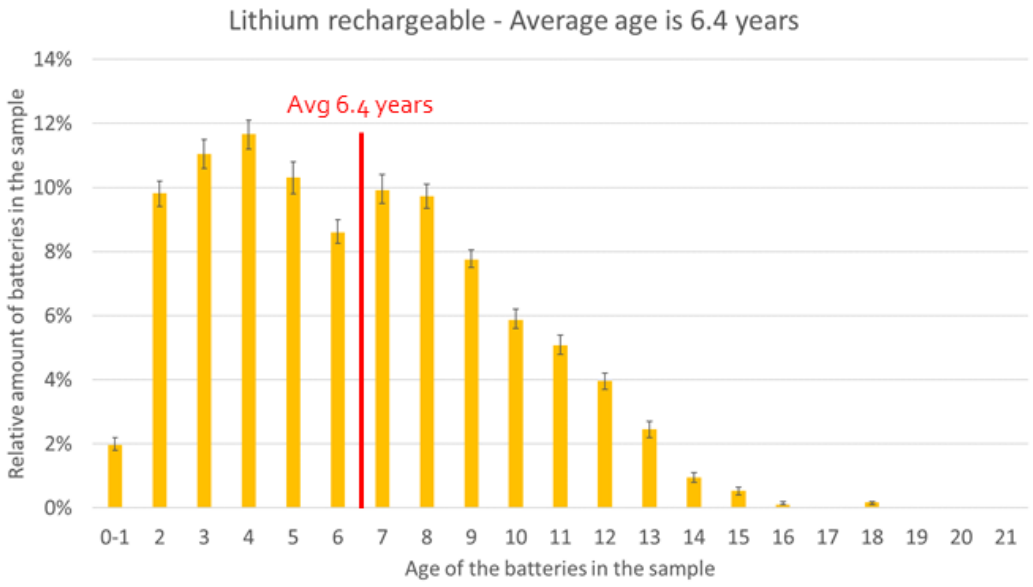


Figure 2: Age distribution of lithium rechargeable batteries.

The European Collection target (EU target) defines the minimum weight that member organizations should collect. As from 2016, it will be set to 45% of the average weight of batteries put on market during the last three years. This means that the current standard on which all targets of European battery collection organizations are based is that batteries should be collected within 3 years after market entry. However, **the sampling analysis**

showed that the length of the battery life cycle is in fact much longer than three years. Also, if the assumption would be true, we would find the proportion of collected batteries that is older than 3 years to be negligible. This is clearly not the case. For example, Figure 3 and Figure 4 show that, for alkaline-zinc and lithium rechargeable batteries respectively, 48% and 77% of the sampled batteries were older than 3 years. To collect 45% of the discarded batteries, batteries that are up to 3 or 5 years old should be collected respectively.

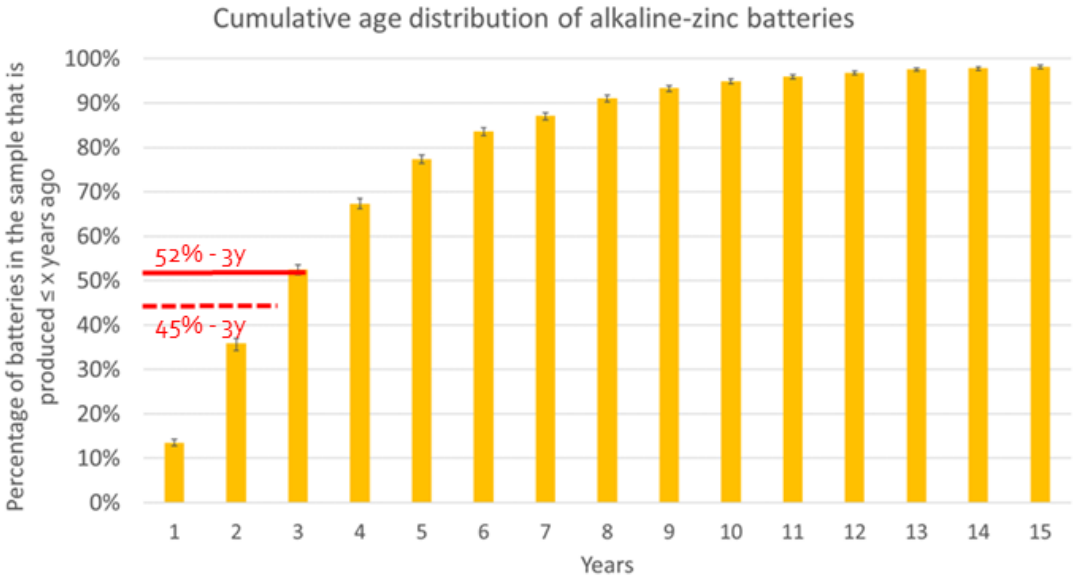


Figure 3: Cumulative age distribution of alkaline-zinc batteries.

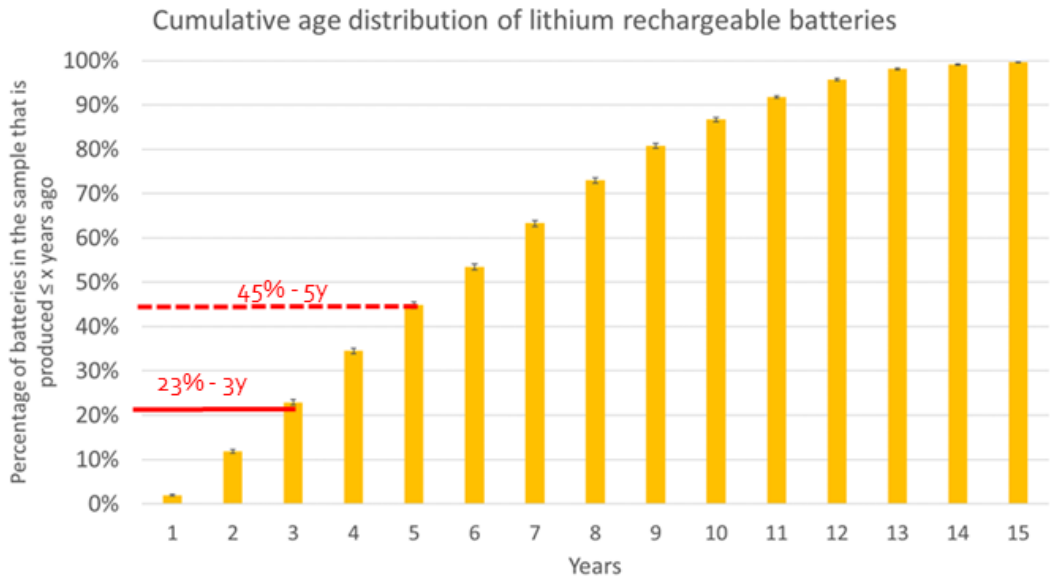


Figure 4: Cumulative age distribution of lithium rechargeable batteries.

The last step consisted of comparing the EU target with the amount of batteries that is at the end of battery life and that has been discarded (the end of life batteries).

The results were **consistent across all included member organizations** in the study.

The overall results can be summarized as follows:

- If the weight of batteries **put on market (POM) is stable,** the average POM during the last three years is very similar to the amount of batteries at the end of life (with the 3-year average deviating at most 13% from the end of life batteries).
- If the weight of batteries **put on market (POM) decreases,** the average POM during the last three years is on average about 40% lower than the amount of batteries at the end of life.
- If the weight of batteries **put on market (POM) increases,** the average POM during the last three years is on average about 50% higher than the amount of batteries at the end of life.

Therefore, the answer to the initial questions is as follows: **the EU target,** as it is currently computed**, is appropriate only for batteries for which the weight put on market is stable** on the long term. If batteries with a very short life cycle existed (flows for which most of the batteries would be discarded within 3 years), the EU target would also be appropriate for batteries with changing put on market weights. Nevertheless, the sampling analysis showed that no chemical family has such a short life cycle.

In all other conditions, **with varying weights put on market and with life cycles longer than 3 years, the manner in which the EU target is calculated is not appropriate**. Instead, we recommend that a target should be used that correctly represents the collection performance, by taking into account the amount of batteries that are end of life and by comparing those with the batteries that are being collected.

1. Introduction

Eucobat is the European association of national collection schemes for batteries. They assure that all waste batteries are collected and recycled in an ecological sound way, and contribute in this way to a better environment. Eucobat represents the interests of these national compliance organizations for batteries at the European level and provides for a platform for co-operation and exchange of information and best practices, in order to optimize the effectiveness of the operations of the member organizations. These member organizations are subject to the **European collection performance target** (EU target)[2].

In this light, a large **sampling study** was set up to evaluate the impact that the battery life cycle has on the amount of batteries that is discarded and, consequently, the collection performance. This study was performed for **six member organizations**: Bebat (Belgium), Corepile (France), GRS (Germany), Stibat (The Netherlands), Ecopilas (Spain) and SNRB (Romania). For each of these six member organizations, the results of the study are represented in individual reports and this report consolidates their findings, in order to extrapolate the results on the European level. More specifically, this report aims at answering the following questions:

- Is the manner in which the EU target is calculated appropriate given the length of the battery life cycle?
- Is the EU target appropriate in case the weight of batteries put on market (POM) changes?

In order to answer these questions, chapter 2 and 3 present the methodology used to determine the life cycle of batteries and the results of this life cycle analysis.

Chapter 4 explains what the EU target is and how the life cycle length and the declarations of the batteries put on market impact the collection performance compared to the EU target.

2. European impact of the study

In this study, six member organizations of Eucobat were included: Bebat (Belgium), Corepile (France), GRS (Germany), Stibat (The Netherlands), Ecopilas (Spain) and SNRB (Romania).

[2] EU target = 45% of the average over 3 years of the weight put on market.
Target to be achieved by 26/09/2016, cfr. Directive 2006/66/EC

These organizations (and countries) were chosen carefully to have a good representation of the market of portable batteries within the European Union. This is true due to the following reasons:

- The included countries cover **different parts of Europe**: Southern Europe (Spain), Western Europe (France, Belgium, The Netherlands), Central-Western Europe (Germany) and Eastern Europe (Romania).[3]
- The included countries cover **48% of the inhabitants** of the EU and **42% of the area**.[4]
- The included countries cover **48% of the total weight of portable batteries put on market** in 2014 in the EU.[5]
- The included countries cover **53% of the total weight** of **collected portable batteries** in 2012 in the EU.[6]



Figure 5: Member organizations from six different countries are included in this study (Belgium, The Netherlands, Germany, Spain, France and Romania).

[3] Both countries with (France, Germany, Romania and Spain) and without (Belgium and The Netherlands) competing collection schemes are included.

[4] Based on Eurostat data of 2014.

[5] Based on POM data of portable batteries in the 28 countries of the European Union in 2014 provided by the European Portable Battery Association (EPBA).

[6] Based on Eurostat data of 2012. Given a different interpretation of the Eurostat data among the different countries, this result should be interpreted with caution.

Some key figures of the included member organizations are given in Table 1.

Table 1: Key figures of the included member organizations.

	Bebat	Corepile	Ecopilas	GRS	SNRB	Stibat
Start	1996	1999 (2003)	2008	1998	2011	1995
Market Share (Portable Batteries)	100%	67%	45%	77%	80%	100%
Collection Rate	55.5%	39.9%	35.6%	45.9%	7.5%	46.1%

Due to these reasons, we are confident that the included countries and collection schemes are a representative subset of the market of portable batteries in the European Union. Therefore, the results of this study that are consistent for the six included countries will also hold for other European countries, which will be further explained in paragraph 4.3. In what follows, the **results of the six countries are consolidated in EU results**. For the sake of conciseness, in the remainder of this report the consolidated results for the six countries will be referred to as 'European' or 'EU' results.

3. Battery life cycle

When analysing the life cycle of batteries, the average battery age is a key figure of interest. Next to the average battery age, the age distribution is a relevant measure as well in the sense that we want to know the amount of batteries being discarded 1, 2, 3… years after production.

In order to answer these questions an extensive sampling study was set up. The next paragraphs will explain how the sampling was performed and will show the results of the analysis.

3.1. Sample selection

Sampling was done by each member organization separately. However, the sampling procedure was similar in all countries and is explained below.

The **first step of the sampling process** consisted of **setting up a stratified sample** of batteries to be studied. This was done in the following manner:

1. Sort the batteries per chemical family
2. Prepare a separate recipient for each chemical family
3. During a period of days, until the target sample size is reached, take a representative (random) sample from each chemical family and put it in the prepared bins.

This was done randomly in order to ensure that each sample would be representative of its chemical family.

Sample selection was done in the first half of 2015.

In this study we only included portable batteries. The chemical families that were used in this study are the following:

- Primary (or non-rechargeable) batteries
    - Alkaline – zinc batteries
    - Primary lithium
- Rechargeable batteries
    - Nickel cadmium
    - Nickel metal hydride
    - Lithium rechargeable
    - Lead

Other chemical families (such as silver oxide batteries) were not included given their small relative amounts. Furthermore, no button cells were sampled because their production date cannot be traced.

The main target of the study was to obtain results at the level of the chemical families and the organizations. Therefore, a **stratified sampling** procedure was used at each organization separately, meaning that the sampling of a chemical family was done independently of the sampling of the other chemical families and independently of sampling by other organizations. Thus, the sample size was determined for each chemical family at each organization individually. For each chemical family-organization combination the sample size was calculated to achieve a **95% confidence level** on the estimate of the battery age with a **5% margin of error**. The required sample sizes were calculated using estimates for average and standard deviation of battery age based on a previous life cycle study. The 95% confidence level indicates that if we would repeat the sampling study 100 times, the confidence interval would contain the true average age of the batteries in the total market 95 times for a given chemical family-organization combination. The 5% margin of error indicates that the boundaries of the confidence interval around the estimate for the average battery age deviate at most 5% from this average for each chemical family-organization combination individually.

Once the samples had been formed, the registration process started: all of the information from each individual battery was registered. Every battery was weighed, all text that could help in identifying the production date of the battery was recorded (production and expiry dates if present, but also brand name, model number, voltage, amperage…) and pictures were taken of the battery. This process is illustrated in the pictures of Figure 5.



Figure 6: Sampling process

In total, over **154,000 batteries** of different chemical families were registered.

After **consolidating all information** for all participating organizations, a selection of manufacturers to contact was set up. This list was a combination of "major" companies that put batteries on the European market and "small" companies, considering representativeness of the sample.

When all of the registered information was consolidated per manufacturer, the information was **sent to the "major" companies** that put batteries on the European market, that is, manufacturers from whom a significant number of batteries were found (70% of the batteries sampled in the six collection schemes included in this study came from 107 out of the 3,646 producers for which batteries could be found in the sample). In order to increase representativeness, 30 additional randomly chosen manufacturers were contacted. These manufacturers were asked to provide the production year of each individual battery. If they didn't have an exact production year, but only the range of years the battery was produced in, the most recent production year was selected. In this way the most conservative year is included in the study. Unfortunately, not all manufacturers could provide us with the production year of their batteries. If a manufacturer didn't provide feedback, production year information was included by checking individual battery pictures. If the production year wasn't found, the battery was excluded. Therefore, the analyses were based on a subset of 46,485 batteries (Table 2).

Table 2: Number of batteries for which a valid production date could be determined. These batteries are included in the results of this study.

Chemical family	Number of batteries
Alkaline-zinc	5,914
Lead	3,774
Lithium rechargeable	19,364
NiCd	4,880
NiMH	7,958
Primary lithium	4,595
Total	**46,485**

During the sampling study both the **sampling error** and the **sample bias** were kept as small as possible. The sampling error (the error that occurs due to the fact that a random sample will almost never be exactly the same as the entire European market of portable batteries) was controlled by the large sample sizes. To keep the sample bias as low as possible, it was attempted to include as much of the sampled batteries in the results as possible. As stated above, however, producers could only provide production dates of a limited amount of the sampled batteries and also the visual check of battery production dates on the pictures could only be done for a small amount of batteries.

It is important to note that for the NiCd and NiMH chemical families, the sample bias is non-negligible because the production date could only be determined (either by the producer, or by checking the battery pictures) for a small amount of the sampled NiCd and NiMH batteries (respectively for 22% and 14% of the sampled batteries). Therefore, the results presented for NiCd and NiMH should be interpreted with caution. Also, producers didn't have an exact production year for many NiCd batteries, but only the range of years the battery was produced in, so the most recent production year was selected. In this way the most conservative year is included in the study.

Also note that it is the production year that is known, not the production day. This lack of precision in the data is, however, negligible for our purposes.

Due to the stratified sampling, the total sample size (and thus the total sample) is **not representative of the total market returns** as the proportion of each chemical family and each organization within the total number of batteries that were sampled does not reflect the European proportions. To overcome this issue, a European sample was constructed based on the six included organizations by bootstrapping the total sample. The amount of batteries of a certain chemical family-organization combination that should be included in the consolidated European sample were determined based on the POM figures of all

chemical families and countries (e.g. if 20% of the alkaline-zinc batteries in the consolidated POM of all six included countries is from France, the European bootstrapped sample of alkaline-zinc batteries should consist for 20% out of batteries coming from the Corepile sample).[7] By doing so, it is assumed that the samples of the collection schemes are representative samples for the countries they operate in and that a European sample can be approximated by a consolidated sample from the six included countries (which was also discussed in chapter 2). The total European sample size for each chemical family was chosen to be equal to the total amount of registered batteries of that chemical family with a valid production date. In this study, the bootstrapping method doesn't allow to calculate confidence intervals that are representative for the total population of discarded portable batteries from which the sample was taken. Therefore, the confidence intervals shown in this report illustrate the spread in the sample by performing the bootstrap method multiple times and can thus be interpreted as a lower limit for the true spread in the total population of discarded portable batteries. However, it was ensured that this method does not reduce the validity of the presented results and interpretations.

It should be noted that the bootstrapped sample is the best possible approximation of a balanced sample to be taken from the six participating collection schemes. Moreover, this bootstrapped sample is, to date, the largest and most representative sample for European market returns to be ever analysed.

3.2. Assumptions

Several assumptions were made in order to be able to perform the analyses of the battery life cycles:

- Battery weight and age are independent within the samples.
  This assumption implies that the conclusions from the analyses in units (number of batteries) are also valid for battery weight.
  Note that the battery weight is not independent of the chemical family.
- On average, batteries are sold 3 months after production.[8]
  This means that we will have to make a difference between the battery age (the time from production to collection) and the usage and hoarding term of batteries (from market entry to collection). This will be explained in more detail in paragraph 3.3.

[7] The actual relative amounts were calculated based on the average POM data of portable batteries between 2008 and 2014 provided by the European Portable Battery Association (EPBA) for the six included countries. The separation of the POM data in different chemical families was based on a general chemical family distribution that was provided by Eucobat.

[8] Based on manufacturer information

- The samples of the six member organizations are representative for their respective countries.
  e.g. the Corepile sample is a valid sample for the total amount of collected portable batteries in France.
- The grouped results and consolidated sample of the six member organizations is representative for the European market.
  By consolidating the results of the six individual organizations into a bootstrapped sample, we conjecture that the results are representative for the 6 countries from which a collection scheme participated and by expansion, the total European market.

3.3. Calculating the average time from market entry to discarding

As explained in the previous paragraph, there is a difference between the battery age and the time from market entry to discarding. The battery age corresponds to the time between production and discarding while, according to battery manufacturers, there is usually a 3-month delay between production and market entry. This is illustrated in the following figure.

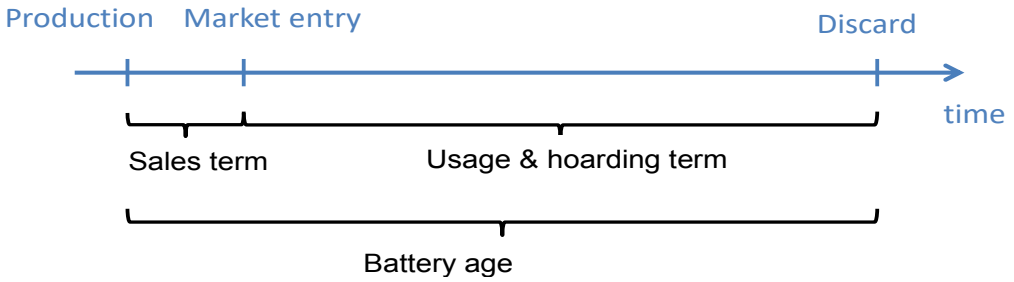


Figure 7: Difference between battery age and usage and hoarding term

In order to estimate the time between the moment the battery is put on the market and the moment it is discarded, the following steps are applied:

1. **Calculate battery age**
   Calculating the age of batteries within the sample:

   Battery age = collection year (2015) - production year

2. **Calculate usage and hoarding term**
   Calculating the usage and hoarding term within the sample:

   Usage and hoarding term = battery age – 0.25 years

   We can then estimate the average usage and hoarding term in the market of batteries by calculating the average usage and hoarding term in the sample. To indicate the confidence of this estimate, we construct a confidence interval at a given

confidence level (in this case at the 95% confidence level). The 95% confidence level indicates that if we would repeat the sampling study 100 times, the confidence interval would contain the true average of the batteries in the market 95 times. The confidence interval is constructed by performing the bootstrap procedure 100 times and defining an interval in which 95% of the average usage and hoarding terms from the 100 iterations are included.

3.4. Calculating the age distribution of batteries

Next to the average usage and hoarding term, the age distribution is a relevant measure as well. More specifically, for all batteries on the market, we want to know what percentage of batteries is younger than 1 year, 2 years, 3 years… In statistics, this would be called a cumulative age distribution. Then, together with the put on market (POM) data it is possible to estimate the relative amount of batteries that is discarded after 1 year, 2 years, 3 years… which is called the discard rate. The discard rates are only calculated at the level of the individual organizations and is discussed in the individual reports of the six member organizations in detail.

The cumulative age distribution is calculated in the following manner:

1. All batteries are sorted into categories based on their age.
2. The proportion of each age category is calculated as well as the confidence interval around this proportion.

3.4.1. Sorting batteries into age categories

In order to sort the batteries into age categories in such a manner that the confidence interval on the cumulative distribution can be calculated, we need to determine for each battery whether its age is larger or smaller than 1, 2, 3 … years. As an illustration, consider the following example with 3 batteries (Table 3).

Table 3: Sorting batteries in age categories. The red colouring indicates an age category in which the given battery is not included whereas the green colouring indicates an age category in which the given battery is included.

	Age	Category1	Category2	Category3	Category4	Category5
Battery1	2	>1 year	≤2 years	≤3 years	≤4 years	≤5 years
Battery2	5	>1 year	>2 years	>3 years	>4 years	≤5 years
Battery3	1	≤1 year	≤2 years	≤3 years	≤4 years	≤5 years

3.4.2. Calculating the proportion of batteries in each age category

The next step consists of calculating the proportion of batteries in each age category. This is done recursively, by calculating the proportion of batteries that is younger than 1 year and repeating this step for all following years. If we use the previous example as an illustration, we would get the following result (Table 4):

Table 4: Example of cumulative battery age distribution in the sample.

Batteries that were collected … after production	Cumulative number of batteries	Proportion
≤ 1 year	1	$\hat{p}_1 = 1/3$
≤ 2 years	2	$\hat{p}_2 = 2/3$
≤ 3 years	2	$\hat{p}_3 = 2/3$
≤ 4 years	2	$\hat{p}_4 = 2/3$
≤ 5 years	3	$\hat{p}_5 = 3/3$…

The last column contains the proportions of batteries in each age category.

Next, we would like to have an idea of the confidence of these measures: Are the observed proportions in the sample ($\hat{p}_i$) representative for the real population proportions (p_i)? In order to do so, a confidence interval was constructed for each proportion. The confidence interval is constructed by performing the bootstrap procedure 100 times and defining an interval in which 95% of the proportions from the 100 iterations are included

3.5. Results

3.5.1. Average usage and hoarding term per chemical family

The figure below shows the average usage and hoarding term for each chemical family. The yellow bars represent the average usage and hoarding term of batteries and the black error bars at the right end represent the confidence interval around this average. For example, looking at alkaline-zinc batteries, we see that their average usage and hoarding term amounts to 4.0 years and that the confidence interval around this average ranges from 3.89 to 4.04 years. The battery age for alkaline-zinc batteries then has a value between 4.14 and 4.29 years (including the sales term of 3 months).

Comparing all chemical families, we see that the average time between market entry and collection varies from 4.0 years to 12.3 years.

There is often a statistically significant difference in the lifetime of the battery depending on the chemical family. This can be seen in Figure 8 from the fact that the confidence intervals represented by the error bars do not overlap. For example, NiCd and lead have an average lifetime that is significantly longer than that of the other batteries. It is important to note that the high average age of the sampled NiCd batteries is partially explained by the prohibition of NiCd batteries in many applications in recent years.[9]

The data on which the figure below is based can be found in Appendix 1: Average usage and hoarding term per chemical family.

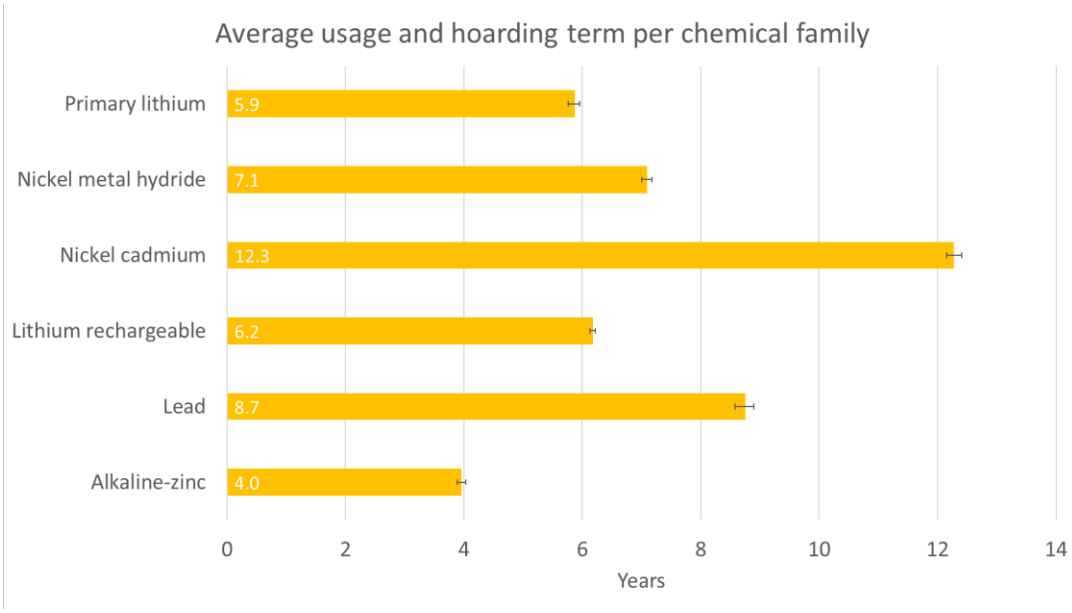


Figure 8: Average usage and hoarding term per chemical family.

In the following table, the detailed results for the different collection schemes is given. It is clear that the results are consistent across different collection schemes.

[9] Automotive batteries: the POM of NiCd batteries is prohibited by the ELV directive (2000). Industrial batteries: the POM of NiCd batteries is not regulated (and thus allowed), except for electrical vehicles, where the use of NiCd batteries is prohibited by the ELV directive (2000). Portable batteries: the POM of NiCd batteries is forbidden since September 26th 2008 (Batteries Directive 2006/66), except for use in emergency and alarm systems, medical equipment and cordless power tools (the POM of NiCd batteries for use in cordless power tools is prohibited since December 31st 2016).

Table 5: Detailed results of average usage and hoarding terms per chemical family in all collection schemes. Alkaline-zinc batteries are almost always the youngest batteries, whereas NiCd batteries are the oldest. The average usage and hoarding term is < 3 years only for alkaline-zinc batteries at SNRB.

Chemfam-Country	Average usage and hoarding term (years)
Alkaline-Zinc	4.0 ± 0.2
Bebat	5.6 ± 0.2
Corepile	4.1 ± 0.2
Ecopilas	3.8 ± 0.2
GRS	3.8 ± 0.2
SNRB	2.4 ± 0.1
Stibat	4.3 ± 0.3
EU	4.0 ± 0.1
Lead	8.2 ± 0.4
Bebat	8.8 ± 0.4
Corepile	10.6 ± 0.4
Ecopilas	7.1 ± 0.3
GRS	8.1 ± 0.4
SNRB	7.1 ± 0.3
Stibat	7.6 ± 0.4
EU	8.7 ± 0.2
Lithium rechargeable	6.3 ± 0.1
Bebat	6.5 ± 0.1
Corepile	6.0 ± 0.1
Ecopilas	4.3 ± 0.1
GRS	6.6 ± 0.1
SNRB	7.3 ± 0.1
Stibat	6.9 ± 0.1
EU	6.2 ± 0.1

Chemfam-Country	Average usage and hoarding term (years)
NiCd	12.3 ± 0.4
Bebat	14.2 ± 0.2
Corepile	12.5 ± 0.6
Ecopilas	11.5 ± 0.2
GRS	12.3 ± 0.5
SNRB	11.5 ± 0.8
Stibat	11.7 ± 0.4
EU	12.3 ± 0.2
NiMH	7.2 ± 0.3
Bebat	5.7 ± 0.1
Corepile	5.3 ± 0.1
Ecopilas	7.5 ± 0.2
GRS	8.2 ± 0.3
SNRB	8.0 ± 0.3
Stibat	8.4 ± 0.5
EU	7.1 ± 0.1
Primary lithium	5.6 ± 0.2
Bebat	5.2 ± 0.2
Corepile	7.5 ± 0.2
Ecopilas	4.4 ± 0.2
GRS	5.2 ± 0.3
SNRB	6.1 ± 0.2
Stibat	5.2 ± 0.2
EU	5.9 ± 0.1

3.5.2. Average usage and hoarding term for the entire market

In order to derive the overall average of the usage and hoarding term we need to know the proportion of each chemical family in the market[10]. This proportion is not known with certainty but the battery declarations (put on market figures) provide a very good indication of these proportions.

[10] If a completely random sample had been taken across all chemical families, a confidence interval could be calculated directly on such a sample. However, the proportion of each chemical family is not representative of the market.

The results are shown in Table 6. The best possible estimation of the average battery age is 5.2 years.

Table 6: Weighted average battery age

	Average usage and hoarding term	Average battery age	Weight of batteries declared in 2014, EPBA [tonnes]
Alkaline-zinc	4.0	4.2	63,976.2
Lead	8.7	9.0	2,444.8
Lithium rechargeable	6.2	6.4	20,609.8
NiCd	12.3	12.5	1,745.0
NiMH	7.1	7.3	6,319.3
Primary lithium	5.9	6.1	1,512.3
Weighted average battery age		5.2	

3.5.3. Age distribution per chemical family

In Figure 9-14 the age distributions for all chemical families is represented. Given that age distributions are relatively wide, it is clear that average age should be complemented with the spread on the age distribution to correctly represent the battery age.

Note that in the following figures battery age is represented and not usage and hoarding term, meaning that the sales term of 3 months is added to calculate the battery age.

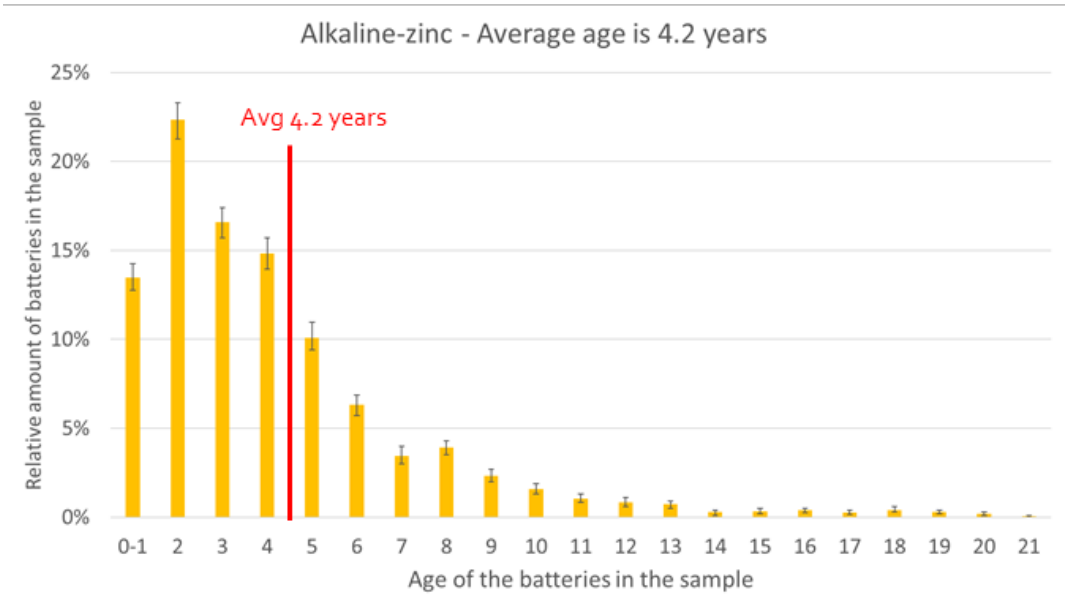


Figure 9: Age distribution of alkaline-zinc batteries.

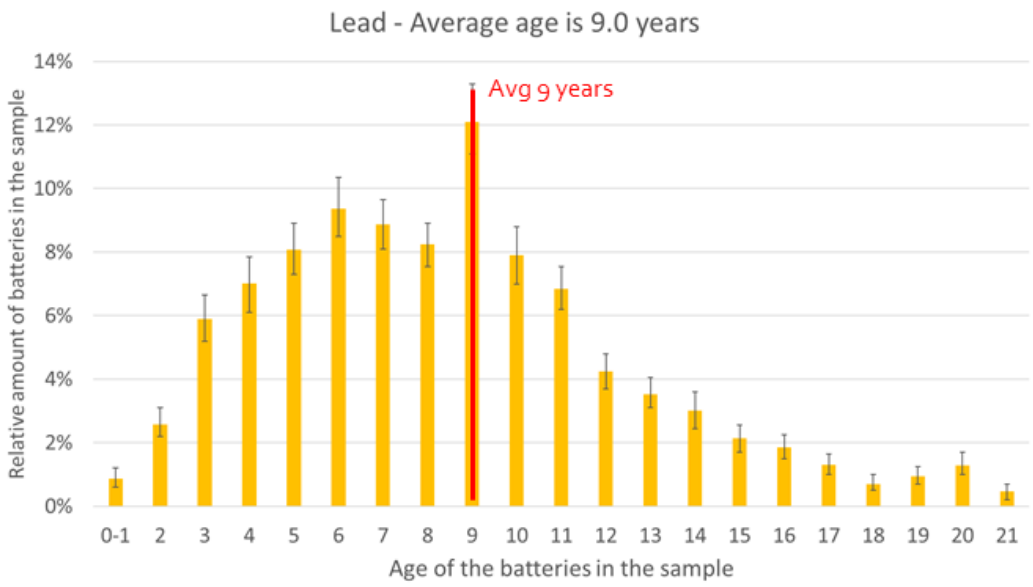


Figure 10: Age distribution of lead batteries.

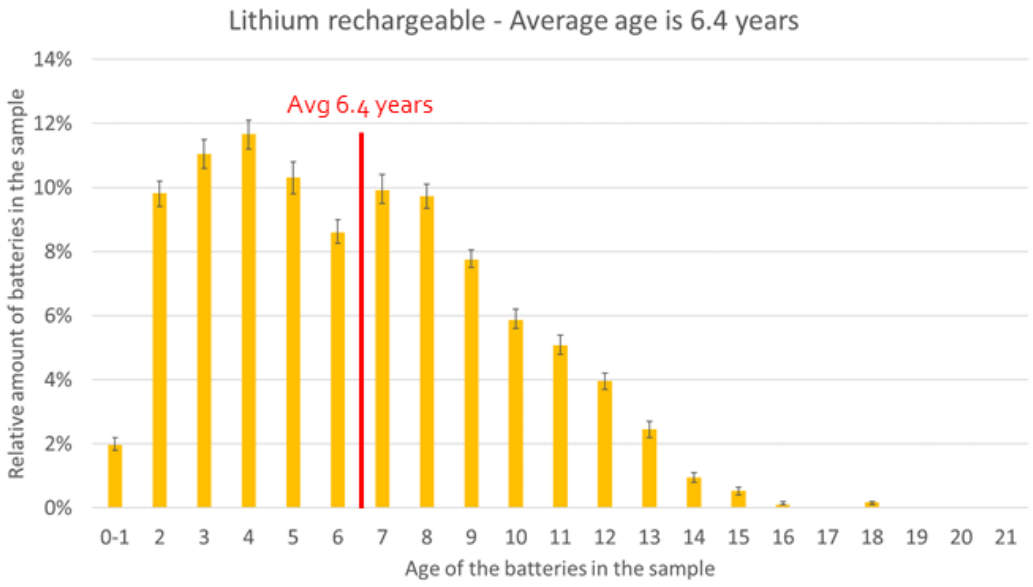


Figure 11: Age distribution of lithium rechargeable batteries.

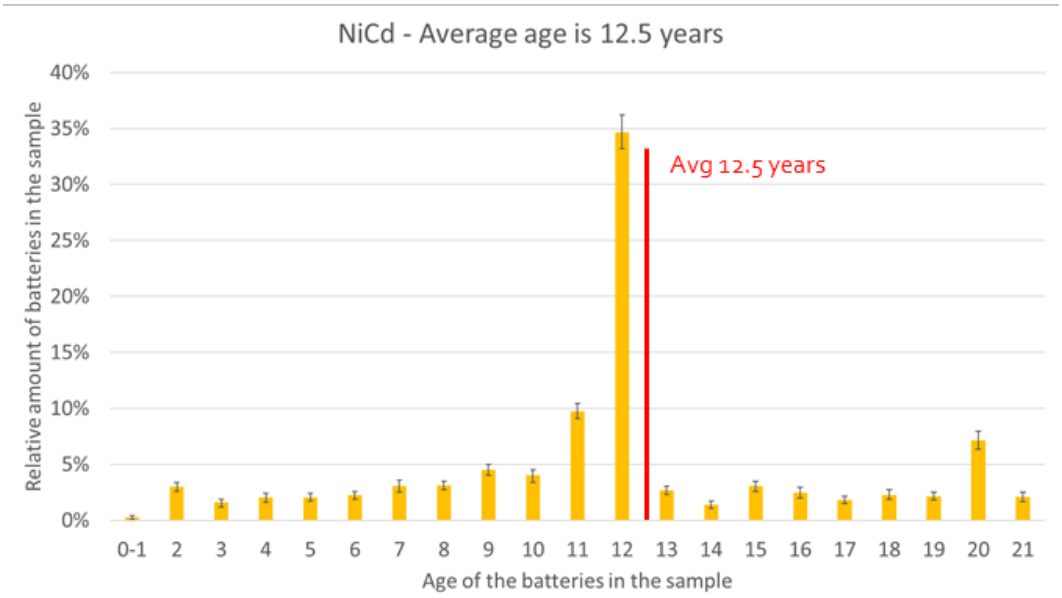


Figure 12: Age distribution of NiCd batteries. The distinct peaks in the age distribution are a result of the sample bias. A production date could be determined for only a limited number of batteries and often only the range of years in which the battery was produced was known. In this case, the most recent production year was selected to include the most conservative year in the study.

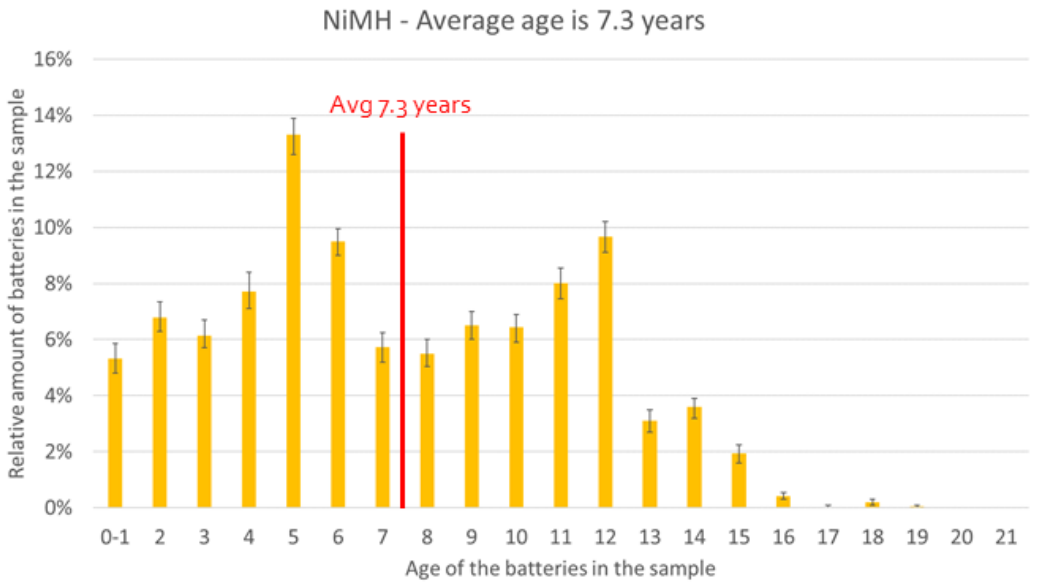


Figure 13: Age distribution of nickel metal hydride batteries.

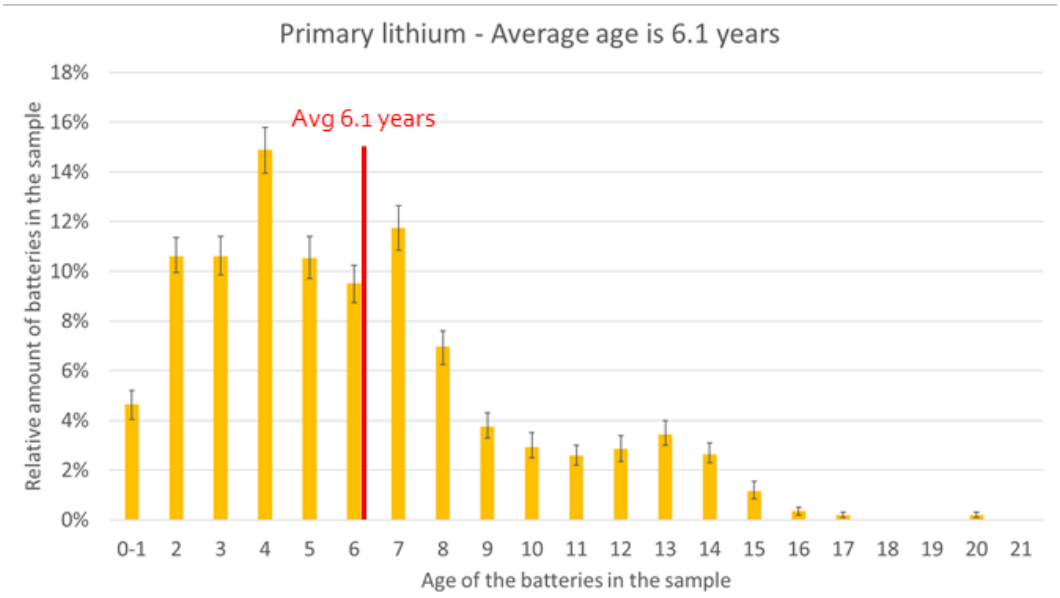


Figure 14: Age distribution of primary lithium batteries.

3.5.4. Cumulative age distribution per chemical family

Next to the average usage and hoarding term, we are also interested in the cumulative age distribution of batteries. More specifically, we want to know what proportion of the collected batteries were produced ≤ 1 year ago, ≤ 2 years ago…

The cumulative age distribution of each chemical family can be found in the graphs below or in the tables in Appendix 2: Cumulative age distributions per chemical family. The yellow bars represent the proportion of collected batteries produced ≤ x years ago (e.g. the first yellow bar is the proportion of batteries produced ≤ 1 year ago). The black error bars represent the 95% confidence interval around this proportion. In red, the amount of batteries in the sample that was produced ≤ 3 years ago is indicated as well as the age of batteries that should be included to collect 45% of the discarded batteries.

Looking at the results for alkaline-zinc batteries (which represents a majority of batteries put on the market) we see that about 52% of the collected batteries is produced ≤ 3 years ago. We also see that many batteries were produced much longer ago. In order to get to 80% of the collected batteries, we have to include batteries that are produced up to 6 years ago.

The same types of observations can be made for all chemical families, but there is a significant difference between the chemical families in the proportion of batteries. For

example, for the proportion of collected batteries that is produced ≤ 3 years ago, the results range from 5% (NiCd) to 52% (alkaline-zinc)[11] (see red bars).

The current standard on which all targets of European battery collection organizations are based is that batteries should be available for collection within 3 years after market entry. If this assumption would be true, we would find the proportion of collected batteries that is older than 3 years to be negligible. This is clearly not the case.

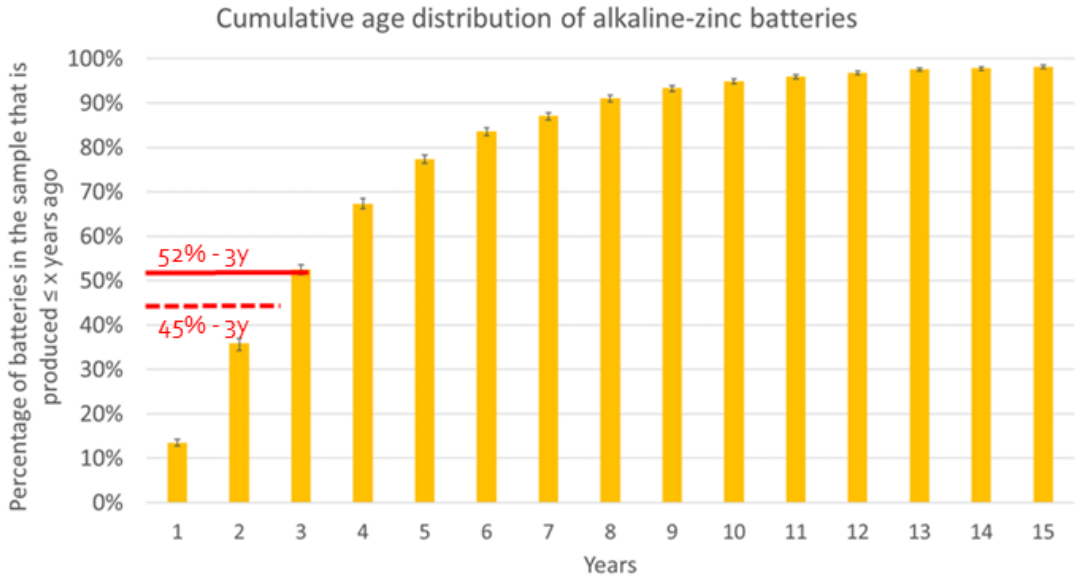


Figure 15: Cumulative age distribution of alkaline-zinc batteries.

[11] Amongst the batteries that are collected by the organizations included in this study: some batteries are not discarded through proper channels or are exported or brought to recyclers through other channels. These batteries are not represented in the sample.

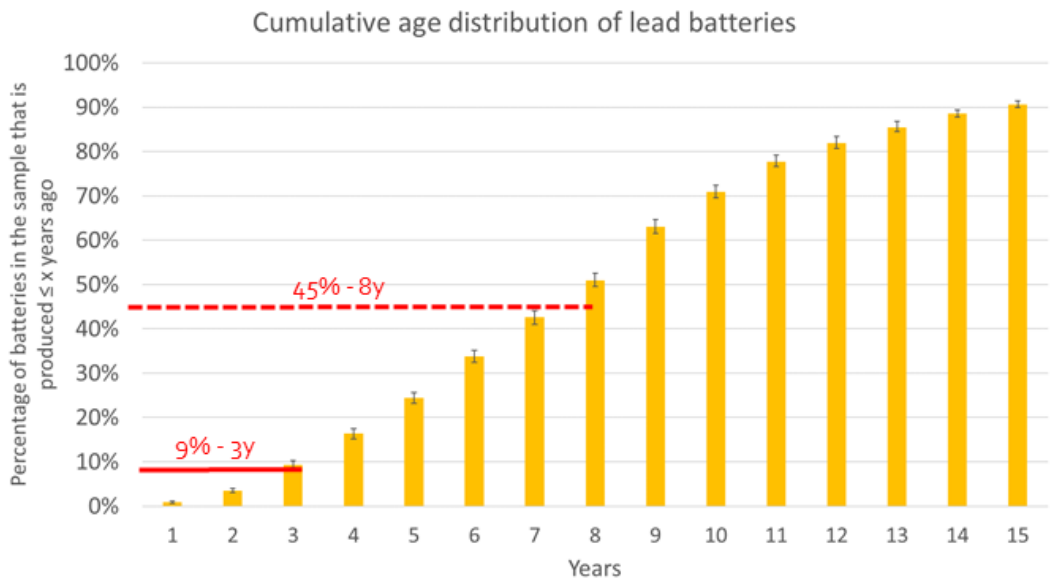


Figure 16: Cumulative age distribution of lead batteries.

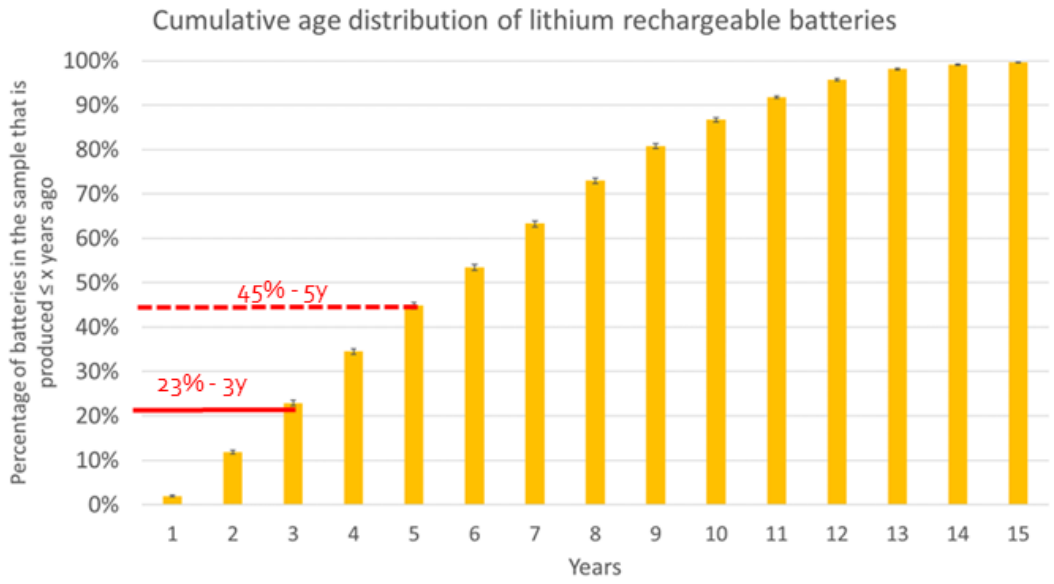


Figure 17: Cumulative age distribution of lithium rechargeable batteries.

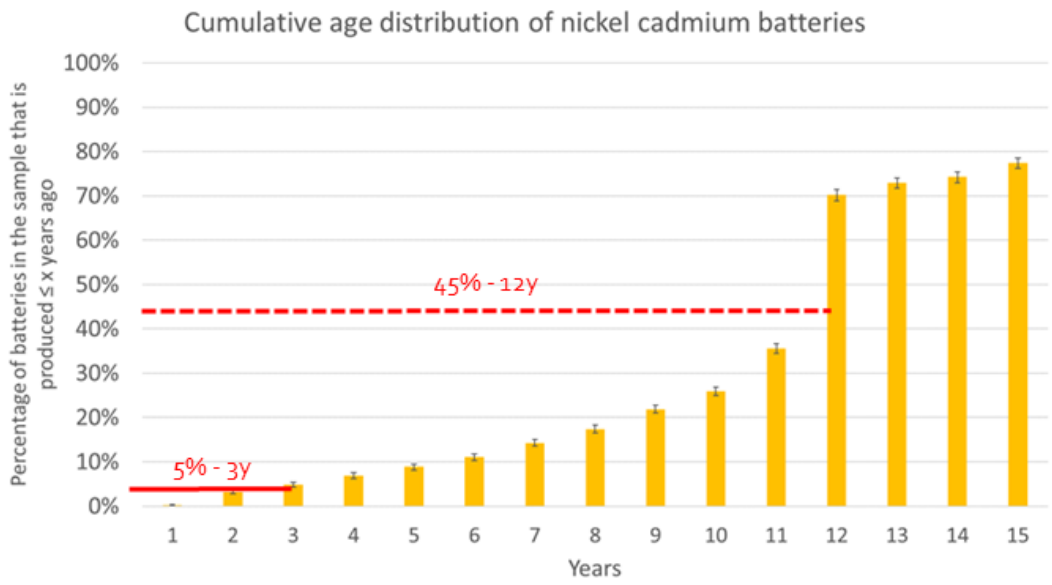


Figure 18: Cumulative age distribution of nickel cadmium batteries.

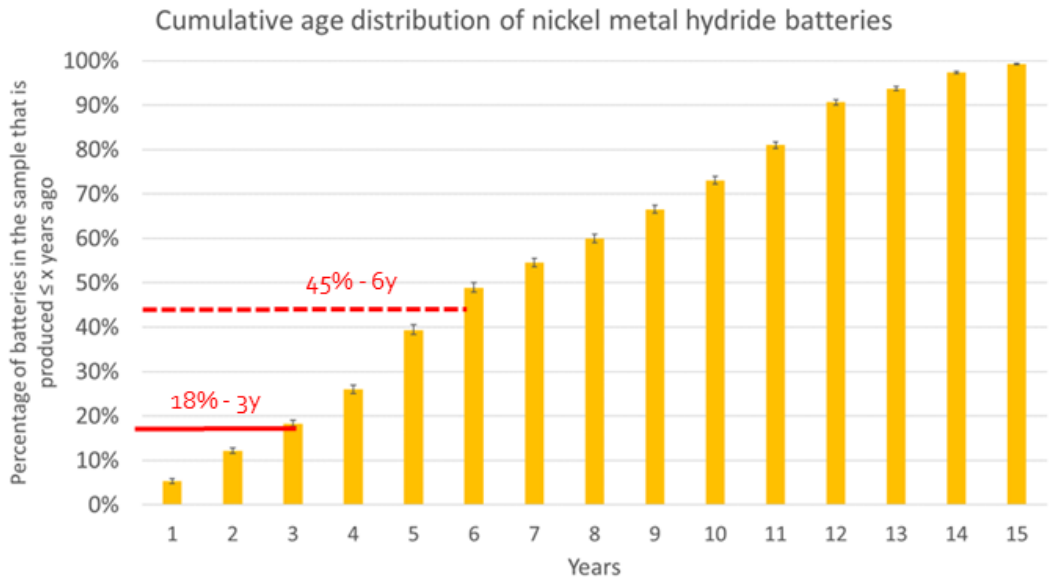


Figure 19: Cumulative age distribution of nickel metal hydride batteries.

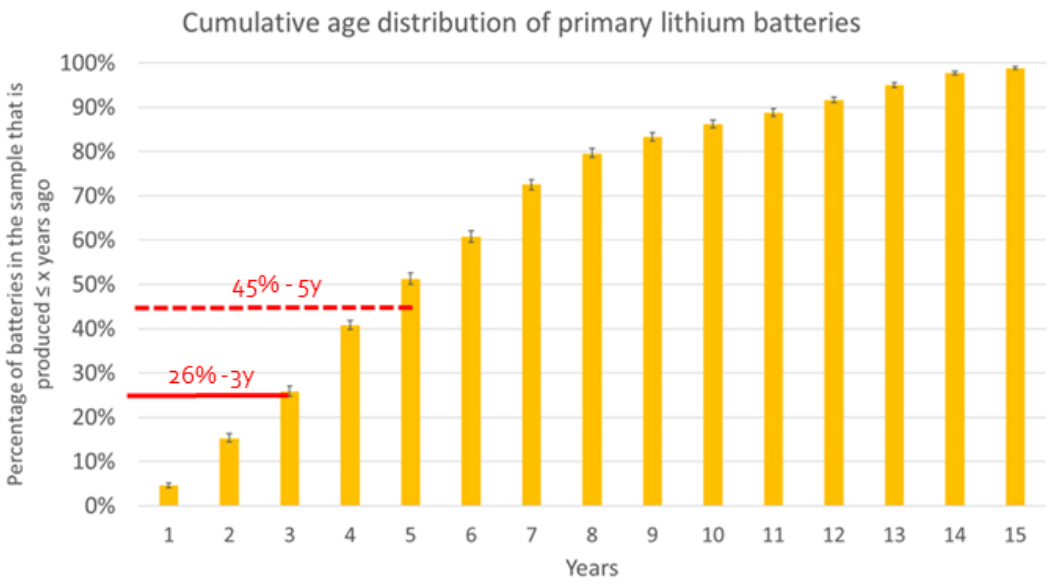


Figure 20: Cumulative age distribution of primary lithium batteries.

In Figure 21, the weighted average cumulative age distribution is given. Only 42% of the collected batteries in the sample are produced ≤ 3 years ago.

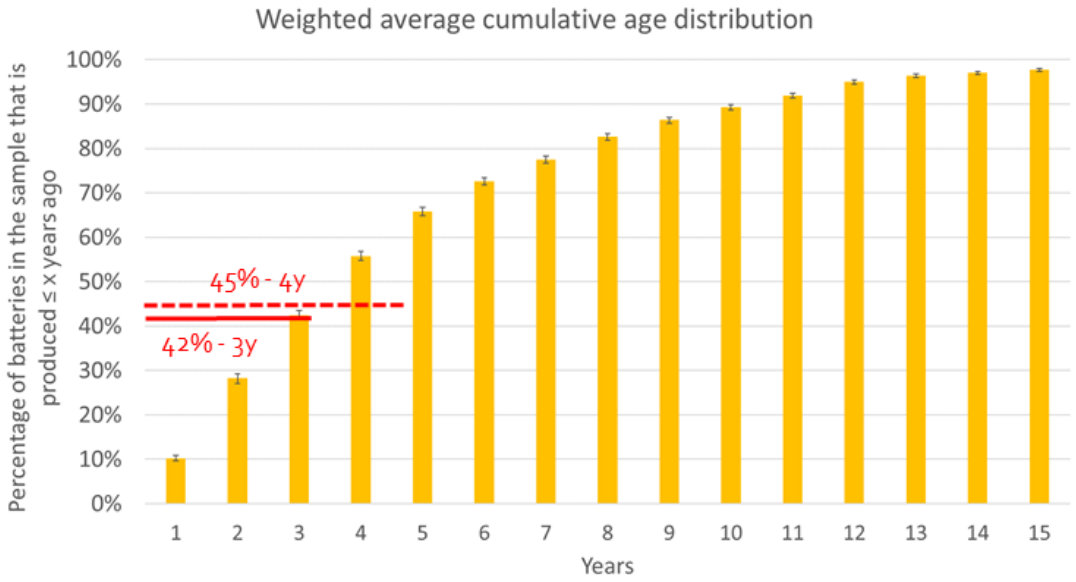


Figure 21: Weighted average cumulative age distribution.

3.5.5. Conclusions of the life cycle analysis

The current standard on which all targets of European battery collection organizations are based is that batteries should be collected within 3 years after market entry. Clearly this does not correspond to current situation.

It is possible to state that at a 95% certainty level the average time between the moment a battery is put on market and the moment it is collected by the member organizations is at least:

- 3.9 years for alkaline-zinc batteries
- 8.6 years for lead batteries
- 6.1 years for lithium rechargeable batteries
- 12.2 years for nickel cadmium batteries. This result has to be interpreted with caution due to the low representativeness of the nickel cadmium sample (see paragraph 3.1).
- 7.0 years for nickel metal hydride batteries. This result has to be interpreted with caution due to the low representativeness of the nickel metal hydride sample (see paragraph 3.1).
- 5.8 years for primary lithium batteries

Furthermore, and also at a 95% certainty level, the proportion of collected batteries that is produced ≤ 3 years ago is at most:

- 54% for alkaline-zinc batteries
- 10% for lead batteries
- 24% for lithium rechargeable batteries
- 5% for nickel cadmium batteries. This result has to be interpreted with caution due to the low representativeness of the nickel cadmium sample (see paragraph 3.1).
- 19% for nickel metal hydride batteries. This result has to be interpreted with caution due to the low representativeness of the nickel metal hydride sample (see paragraph 3.1).
- 27% for primary lithium batteries

Based on these analyses, the best possible estimation of the average battery age is **5.2** years.

4. Impact of battery life cycle on collection performance

The collection performance is expressed as the weight of portable batteries collected this year in relation to the weight that has been sold (or "put on the market, POM"). The minimum collection performance is set by the EU target which is explained in paragraph 4.1.

In the individual reports of the six member organizations, we evaluated in detail whether the life cycle had a significant impact on the collection performance. The analysis that was made is explained in paragraph 4.2. The results of the individual organizations are very consistent which is why the results at the European level for this analysis are limited to a summary of the consistent results across all individual organizations. These results are presented in paragraph 4.3.

4.1. EU target

The EU target for 2016 was defined by the European Parliament and the Council (Directive 2006/66/EC). Its formula is based on the average weight of batteries that entered the market in the previous 3 years. More specifically, the formula is the following:

EU Target = 45% * (average over 3 years of the weight put on market)

Let's consider the following example.

Table 7: Example of EU target calculation

Year	Weight put on market
2014	1,000 T
2015	2,000 T
2016	3,000 T

The average yearly weight put on market = (1,000 T+2,000 T+3,000 T)/3 years = 2,000 T/year Therefore, the European collection target for 2016 (EU target) = 45%*2,000 = 900 T. This means that in order to reach the collection target, the collection organization should collect 900 T in 2016.

4.2. End of life batteries

In the individual reports of the six participating collection schemes, we evaluated in detail whether the life cycle had a significant impact on the collection performance. Therefore, we wanted to know whether the 3-year average POM was significantly different from an estimate of the amount of batteries that is discarded based on the life cycle. This amount of batteries that is at the end of the life cycle and discarded is named the **end of life batteries** and it is our best estimate of the true amount of batteries that is discarded. Comparing the end of life batteries with the 3-year average POM will allow us to evaluate the influence of the life cycle on the collection performance.

Calculating the end of life batteries was done in the following way for the six member organizations:

$$End\ of\ life\ batteries = \sum_{i=X-n}^{X} POM_i * DR_{X-i}$$

Where,

- X the year in which the end of life batteries is determined.
- n the amount of historic data in years that is used. If we calculate the end of life batteries in 2015 and we use POM data until 1999, n is 16.
- POM_i is the POM data of year i.

DR_{X-i} is the discard rate of batteries produced in year i and discarded in year X. This relative amount (ranging from 0%-100%) indicates the proportion of the POM of year i that is discarded in year X. For example, when calculating the end of life batteries in 2015, DR_0 indicates the relative amount of batteries that was produced and discarded in 2015. DR_1 indicates the relative amount of batteries that was produced in 2014 and discarded in 2015. DR_2 indicates the relative amount of batteries that was produced in 2013 and discarded in 2015 and so on.

A detailed explanation of the estimation of the discard rates and the calculation of the end of life batteries is given in the individual reports for the six participating collection schemes.

4.3. Results

In Appendix 3: Overview of end of life results for the individual organizations, a brief overview is given of the main results for the six individual organizations. The results are consistent across all organizations and chemical families:

- For a chemical family-organization combination with a **stable POM**, the 3-year average POM is very similar to the amount of batteries at the end of life (with the 3-year average deviating at most 13% from the end of life batteries). Therefore, the EU target amounts to about 45% of the amount of end of life batteries.
- For a chemical family-organization combination with a **decreasing POM**, the 3-year average POM is on average about 40% lower than the amount of batteries at the end of life. Therefore, the EU target amounts to less than 45% of the amount of end of life batteries.
- For a chemical family-organization combination with an **increasing POM**, the 3-year average POM is on average about 50% higher than the amount of batteries at the end of life. Therefore, the EU target amounts to more than 45% of the amount of end of life batteries.

These results are consistent for all chemical family-organization combinations and are summarized in the paragraphs below.

4.3.1. Comparing 3-year average POM and end of life batteries

By calculating the end of life batteries for the years 2012 to 2015 and for all chemical families and organizations, we obtained results as shown in the figures below (Figure 22-24). The

yellow line represents the amount of end of life batteries. They are calculated using the discard rates, as illustrated in paragraph 4.2.

It is clear that when the weight put on market (POM) has been stable for the last decade (which is the case for alkaline-zinc batteries in several countries, see example in Figure 22), the amount of end of life batteries is also very stable and close to the quantities of 3-year average POM.

In case of increasing POM (e.g. lithium rechargeable batteries for Bebat, see Figure 23), the amount of end of life batteries is lower than the 3-year average POM because many batteries from the years 1999-2011 are being discarded during 2012-2015: paragraph 3.5 showed that the average age of discarded lithium rechargeable batteries is 6.4 years and that 19% of the lithium rechargeable batteries in the market is older than 9 years.

Finally, if the quantities POM decrease (e.g. NiCd for GRS, see Figure 24), we see that the amount of end of life batteries is higher than the 3-year average POM. This is because many batteries from the years 1999-2011 are being discarded during 2012-2015: paragraph 3.5 showed that the average age of discarded nickel cadmium batteries is 12.5 years and that 27% of the nickel cadmium batteries in the market is older than 13 years.

It is clear that **when the weight POM varies, the battery life cycle has an important impact on what amount of batteries is at the end of life**. However, if the weight POM is stable, the length of the life cycle does not impact the amount of end of life batteries.

The focus of the next paragraph is to compare the EU target (based on a 3-year average POM) and the amount of end of life batteries (based on the life cycle analysis).

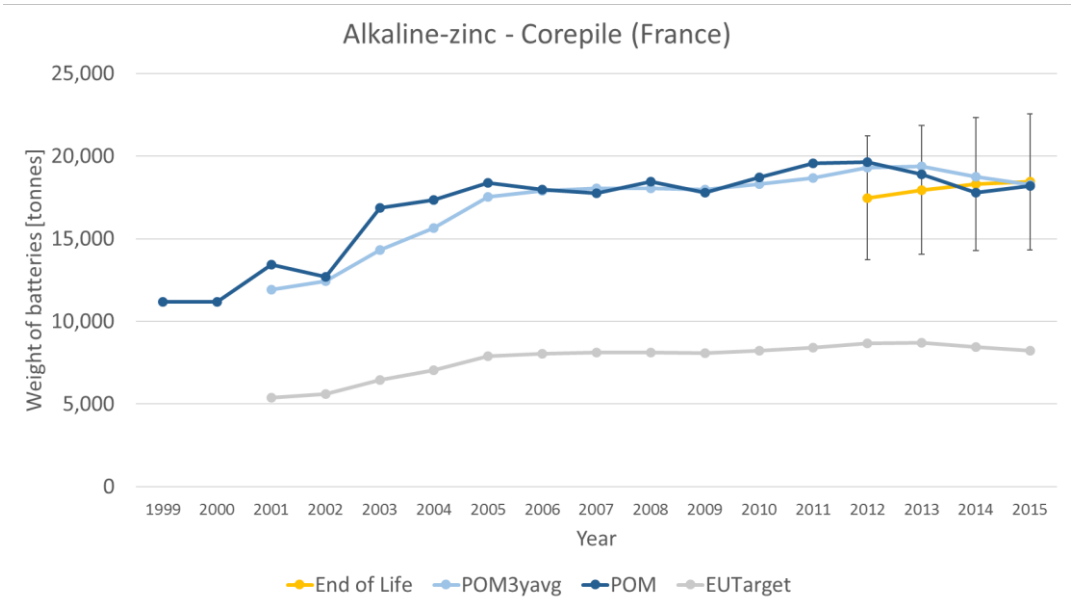


Figure 22: POM, 3-year average of POM, EU target and end of life alkaline-zinc batteries in France (Corepile). Due to the stable POM, the end of life batteries is similar to the 3-year average POM resulting in an EU target that is around 45% of the end of life batteries.

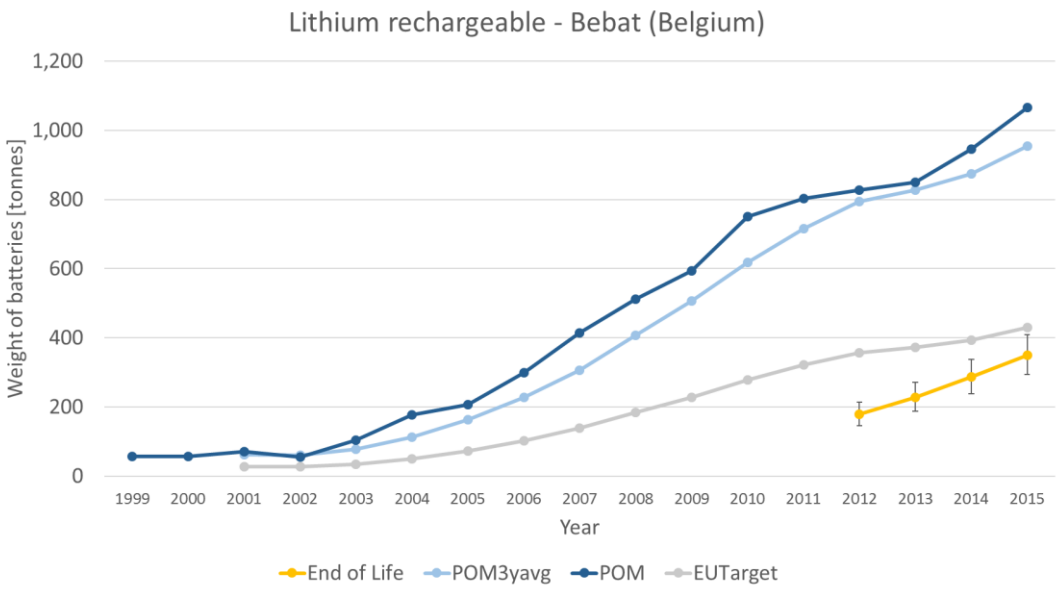


Figure 23: POM, 3-year average of POM, EU target and end of life lithium rechargeable batteries in Belgium (Bebat). Due to the increasing POM, the end of life batteries is lower than the 3-year average POM resulting in an EU target that is higher than 45% of the end of life batteries.

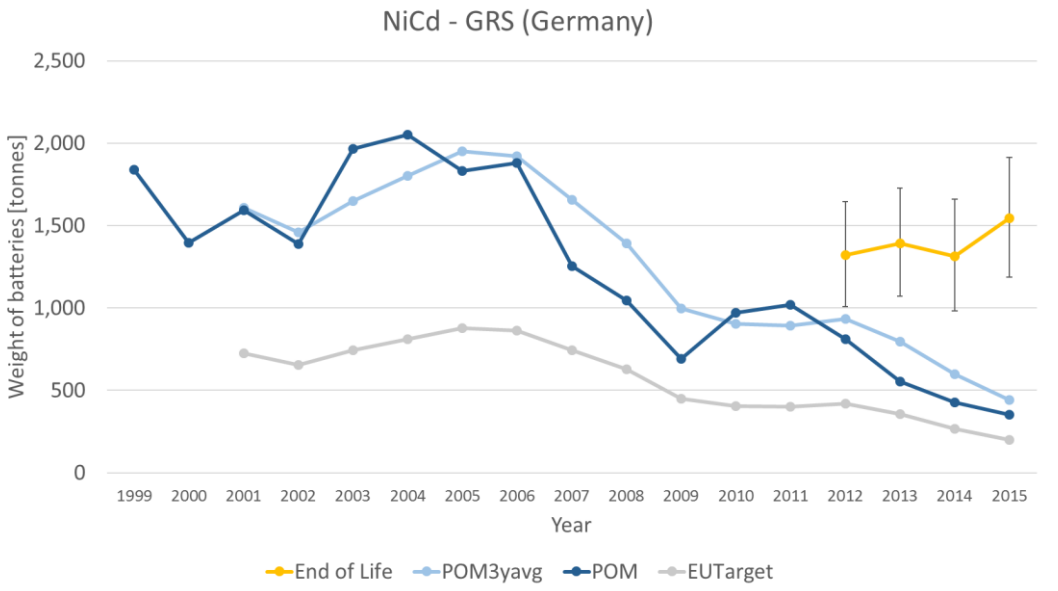


Figure 24: POM, 3-year average of POM, EU target and end of life nickel cadmium batteries in Germany (GRS). Due to the decreasing POM, the end of life batteries is higher than the 3-year average POM resulting in an EU target that is lower than 45% of the end of life batteries.

4.3.2. Comparing EU target and the end of life batteries

In many countries, for alkaline-zinc batteries the weight POM is stable which means that the 3-year average of POM and the end of life batteries are similar to the yearly POM. The result is that the EU target is about 45% of the end of life batteries.

With decreasing volumes, e.g. NiCd in Germany, the previous statements do not hold: more batteries are at the end of life than put on the market. Due to a life cycle that is longer than 3 years, this means that the 3-year average is lower than the end of life batteries. In terms of collection performance, to reach the EU target, less than 45% of the end of life batteries should be collected. However, remember that these flows are diminishing. This means that the importance of these flows in the overall performance of collection organizations will also diminish and, in the end, have a negligible (although positive) impact.

Finally, when volumes increase (e.g. lithium rechargeable in Belgium), the opposite effect can be observed: less batteries are at the end of life than put on the market. Due to the long life cycle of batteries, this means that the 3-year average is higher than the end of life batteries. With lithium rechargeable, the effect of the increase in POM and long life cycle can be so extreme that the amount of end of life batteries is even lower than the EU target (Figure 23): in order to reach the EU target, a collection organization would have to collect more than the total amount of batteries being discarded. Clearly, this is not possible. Using the EU target for increasing flows means that the target is very hard and may even be impossible to reach. Currently, the proportion of these flows in the total weight POM is still limited. However, if the current trend continues, they will make up a larger part of the total weight POM and this problem will become more acute.

5. Conclusion

Based on the results of the life cycle analysis, we can assert that the assumption according to which all batteries are collected within three years following their market entry does not hold. Usually, the battery age is much longer than that: the best possible estimation of the average battery age amounts to **5.2 years**.

The life cycle analysis also allowed us to answer the questions stated in the introduction, that is:

- Is the manner in which the EU target is calculated appropriate given the length of the battery life cycle?
- Is the EU target appropriate in case the weight put on market (POM) changes?

The EU target, as it is currently computed, is appropriate for batteries for which the volumes put on market (POM) are stable on the long term. If battery flows with a very short life cycle existed, say flows for which almost all batteries would be discarded within 3 years, the EU target would also be appropriate for batteries with changing put on market volumes. Indeed, the 3-year average would take any relevant variations of POM into account. Nevertheless, the sampling analysis showed that no chemical family has such a short life cycle.

In all other conditions that is, with a varying POM and with life cycles longer than 3 years, the manner in which the EU target is calculated is not appropriate. Instead, we recommend that a target should be used that correctly represents the collection performance, by taking into account the amount of batteries that are end of life and by comparing those with the batteries that are being collected.

6. Appendices

6.1. Appendix 1: Average usage and hoarding term per chemical family

In years	Alkaline-Zinc	Lead	Lithium rechargeable	NiCd	NiMH	Primary Lithium
Sample Size (n)	5,914	3,774	19,364	4,880	7,958	4,595
Sample Mean	4.0	8.7	6.2	12.3	7.1	5.9
Confidence Level	0.95	0.95	0.95	0.95	0.95	0.95
Lower Limit	3.9	8.6	6.1	12.2	7.0	5.8
Upper Limit	4.0	8.9	6.2	12.4	7.2	6.0

6.2. Appendix 2: Cumulative age distributions per chemical family

Alkaline-Zinc	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years
<=x year	13%	36%	52%	67%	77%	84%	87%	91%	93%	95%	96%	97%	98%	98%	98%
Lower limit <=x year (95% certainty)	13%	34%	51%	66%	76%	83%	86%	90%	93%	94%	96%	96%	97%	97%	98%
Upper limit <=x year (95% certainty)	14%	37%	54%	68%	78%	84%	88%	92%	94%	96%	96%	97%	98%	98%	99%

Lead	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years
<=x year	1%	3%	9%	16%	24%	34%	43%	51%	63%	71%	78%	82%	86%	89%	91%
Lower limit <=x year (95% certainty)	1%	3%	9%	15%	23%	32%	41%	50%	62%	70%	77%	81%	84%	88%	90%
Upper limit <=x year (95% certainty)	1%	4%	10%	17%	26%	35%	44%	53%	65%	72%	79%	83%	87%	89%	91%

Lithium rechargeable	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years
<=x year	2%	12%	23%	35%	45%	53%	63%	73%	81%	87%	92%	96%	98%	99%	100%
Lower limit <=x year (95% certainty)	2%	11%	22%	34%	44%	53%	63%	72%	80%	86%	91%	95%	98%	99%	100%
Upper limit <=x year (95% certainty)	2%	12%	24%	35%	46%	54%	64%	74%	81%	87%	92%	96%	98%	99%	100%

NiCd	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years
<=x year	0%	3%	5%	7%	9%	11%	14%	17%	22%	26%	36%	70%	73%	74%	77%
Lower limit <=x year (95% certainty)	0%	3%	4%	6%	8%	10%	14%	17%	21%	25%	35%	69%	72%	73%	76%
Upper limit <=x year (95% certainty)	0%	4%	5%	8%	10%	12%	15%	18%	23%	27%	37%	71%	74%	75%	79%

NiMH	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years
<=x year	5%	12%	18%	26%	39%	49%	55%	60%	67%	73%	81%	91%	94%	97%	99%
Lower limit <=x year (95% certainty)	5%	12%	18%	25%	38%	48%	54%	59%	66%	72%	80%	90%	93%	97%	99%
Upper limit <=x year (95% certainty)	6%	13%	19%	27%	41%	50%	56%	61%	67%	74%	82%	91%	94%	98%	99%

Primary Lithium	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years
<=x year	5%	15%	26%	41%	51%	61%	73%	80%	83%	86%	89%	92%	95%	98%	99%
Lower limit <=x year (95% certainty)	4%	14%	25%	40%	50%	60%	71%	79%	82%	85%	88%	91%	95%	97%	99%
Upper limit <=x year (95% certainty)	5%	16%	27%	42%	53%	62%	74%	81%	84%	87%	90%	92%	96%	98%	99%

6.3. Appendix 3: Overview of end of life results for the individual organizations

In this appendix, a brief overview is given of the main results for the six individual organizations. The results are consistent across all organizations and chemical families:

- For a chemical family-organization combination with a **stable POM**, the 3-year average POM is very similar to the amount of batteries at the end of life (with the 3-year average deviating at most 13% from the end of life batteries), which is indicated in yellow. Therefore, the EU target amounts to about 45% of the amount of end of life batteries.
- For a chemical family-organization combination with a **decreasing POM**, the 3-year average POM is on average about 40% lower than the amount of batteries at the end of life, which is indicated in grey. Therefore, the EU target amounts to less than 45% of the amount of end of life batteries.
- For a chemical family-organization combination with an **increasing POM**, the 3-year average POM is on average about 50% higher than the amount of batteries at the end of life, which is indicated in brown. Therefore, the EU target amounts to more than 45% of the amount of end of life batteries.

Bebat 2015 [tonnes]	Alkaline-Zinc	Lead	Lithium rechargeable	NiCd	NiMH	Primary Lithium
POM	Stable	Decreasing	Increasing	Decreasing	Increasing	Increasing
End of life batteries	2,722.5	158.2	350.3	452.8	270.2	23.2
POM 3-year average	2,758.1	108.9	953.5	151.5	277.7	40.9
EU target / End of life	46%	31%	123%	15%	46%	78%

Corepile 2015 [tonnes]	Alkaline-Zinc	Lead	Lithium rechargeable	NiCd	NiMH	Primary Lithium
POM	Stable	Increasing	Increasing	Increasing	Increasing	Increasing
End of life batteries	18,439.4	0.8	40.8	81.3	665.0	85.6
POM 3-year average	18,278.3	409.2	952.3	120.8	906.8	135.9
End of life / EU target	45%	18400%	1046%	67%	61%	71%

Ecopilas 2015 [tonnes]	Alkaline-Zinc	Lead	Lithium rechargeable	NiCd	NiMH	Primary Lithium
POM	Decreasing	Stable	Increasing	Decreasing	Stable	Stable
End of life batteries	4,859.2	38.6	1,131.5	543.9	341.8	31.3
POM 3-year average	3,863.2	43.1	1,342.7	362.4	316.7	35.3
End of life / EU target	36%	49%	53%	30%	42%	52%

GRS 2015 [tonnes]	Alkaline-Zinc	Lead	Lithium rechargeable	NiCd	NiMH	Primary Lithium
POM	Stable	Increasing	Increasing	Decreasing	Increasing	Increasing
End of life batteries	22,935.1	701.0	2,691.8	1,543.8	1,758.6	244.9
POM 3-year average	23,628.9	812.4	5,675.7	443.7	2,240.4	358.4
End of life / EU target	46%	52%	95%	13%	57%	66%

SNRB 2015 [tonnes]	Alkaline-Zinc	Lead	Lithium rechargeable	NiCd	NiMH	Primary Lithium
POM	Stable	Stable	Increasing	Decreasing	Stable	Increasing
End of life batteries	1,205.7	17.1	67.0	9.2	8.4	4.1
POM 3-year average	1,176.6	16.1	147.8	5.0	8.6	4.9
End of life / EU target	44%	42%	99%	24%	46%	54%

Stibat 2015 [tonnes]	Alkaline-Zinc	Lead	Lithium rechargeable	NiCd	NiMH	Primary Lithium
POM	Stable	Decreasing	Stable	Decreasing	Decreasing	Increasing
End of life batteries	4,911.4	130.0	1,301.0	341.1	464.7	128.1
POM 3-year average	5,113.8	85.2	1,320.6	167.2	328.7	213.4
End of life / EU target	47%	29%	46%	22%	32%	75%