‘Available For Collection’ study

on alternative collection targets for waste portable and light means of transport batteries

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Foreword

This report is the Deliverable 6.1 of the Administrative Agreement (AA) number "JRC Nº 35889 – 2020 / ENV N° 070201/2020/840561/AA/ENV.B.3" between DG ENVIRONMENT and JRC entitled "Support for Circular Economy Action Plan 2.0- Part 1: Short term actions".

This technical report is the first output of WP6 *("Development of calculation rules for separate collection (based on available for collection) for portable batteries and batteries for light means of transport and estimate of levels of collection targets"*) of the AA. It summarises the findings of the assignment including provision of an initial dataset comparing alternative methodologies to measure separate collection of portable batteries and impacts on possible targets. The work was carried out between January and June 2021.

Acknowledgements

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Executive summary

This study provides the technical background to consider the setting of a collection target for portable batteries and batteries powering light means of transport (LMT), in the light of the evolution of their market share. This work contributes to the preparation of the implementation of the draft Battery regulation proposed by the European Commission in December 2020, especially concerning collection provisions for waste portable batteries. This study is intended to provided additional evidence to the discussion on targets for the collection of waste batteries, in addition to the information presented in the EC Document SWD(2020)335.

The Commission proposal for a Regulation on Batteries (COM(2020)798 final) includes targets for the collection rate of waste portable batteries based on the Batteries Directive (EC/2006/66), which makes use of the Placed On The Market approach (POM). For the moment, these targets exclude batteries powering Light Means of Transport (LMT). Instead, the proposal contains a review clause that requires the setting of a separate collection target for waste batteries powering LMT in the light of the evolution of the market. This review could consider introducing a calculation methodology for the calculation of the separate collection rate with a view to reflecting the quantity of waste batteries available for collection.

In view of the initial reactions from the EU co-legislators, the Commission took on the commitment to explore the possibility to establish collection rate targets based on the quantities available for collection, including as regards LMT batteries, in the ongoing legislative process.

The assessment of a possible definition of batteries in LMT products, their potential market evolution and various options for modernising the collection targets for waste portable and LMT batteries aims therefore to support that process. Due to the complexity of the topic and in order to disentangle various factors mutually affecting both the definition of LMT and the collection target, a structured reasoning is hereby proposed in this report supporting the decision process, substantiated by a parallel quantitative assessment.

Regarding the definition of LMT products and their categorisation, 4 consecutive questions are formulated and then answered in the form of decision options with documentation related to:

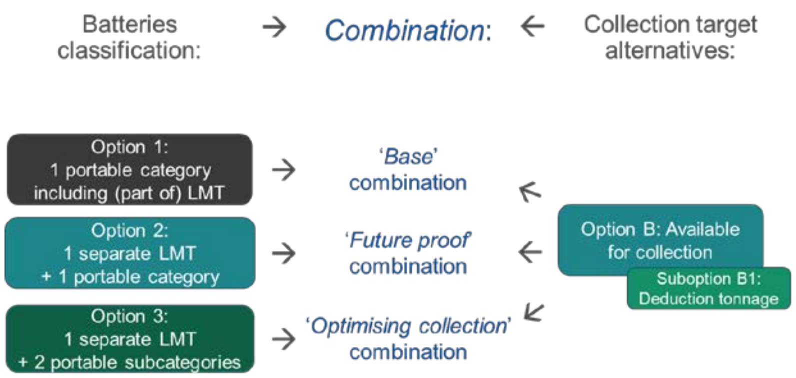
i) The need for a dedicated collection category;
ii) The basis for possible definitions, e.g. related to function, weight and/or capacity;
iii) Definition of limit values and;
iv) Whether revision and update procedures would be required.

A similar approach is taken following a second **set of 4 consecutive questions related to collection targets**:

v) The need for an alternative collection target basis;
vi) Alternative target bases, e.g. related to placed-on-market and/or waste generation potential;
vii) Possible target levels, e.g. 65% of placed-on-market in 2025, 70% in 2030, and;
viii) The need for a future revision or not.

Based on the evaluation of various options and forecasting of various market scenarios, it is concluded that due to increasing sales of rechargeable and LMT batteries, plus potentially more durable primary batteries as well, there will be a growing **discrepancy** between the placed on the market (POM) volumes and the waste volume becoming available later. This means that the currently proposed POM based collection target, based on 3 preceding years of sales, will not be 'steadily ambitious', but relatively more challenging for the years 2025 and 2030 when the newer target levels are respectively set at 65% and 70%. Reversely, in later years it will become less challenging. This equally applies in case the market for portable batteries would either decline, or grow more rapidly compared to the Medium Demand Scenario and baseline of this report. In short: **the more dynamic the future market** of LMT and portable batteries, **the more reason to consider an Available for Collection (AfC) based target** that more accurately reflects actual waste battery volumes.

By combining the most logic and preferred outcomes of each of the 8 key questions mentioned above, the following 3 'most logical' combinations are derived, representing different ambition levels for substantiation of an alternative collection target definition, as presented here:



- The 'base combination' applies in case **no additional category** would be created for LMT batteries. In this case, it is recommended to classify as portable batteries all those batteries used in non-type approved LMT products, like small personal light electric vehicles (including monowheels, hoverboards, unicycles, e-scooters, e-bikes including those with throttles (L1e-A), plus those batteries used in LMT products in the categories L1eB and higher (including speed-pedelecs and 2-wheeled e-mopeds), with a battery weight below 8 kg. Subsequently, all larger batteries used in 3-wheeled e-mopeds and heavier would be classified as EV batteries. For the collection target itself, keeping the original ambition for the total volume would correspond with an AfC based target for portable (including LMT) batteries at 70% of AfC by 2025 and 75% of AfC by 2030. For this to be implemented, a common methodology would need to be developed. It is anticipated that no review clause may be needed, possibly except for developing implementation guidance for the deduction of non-collectable flows like export for reuse in the necessary monitoring protocols.

- The 'future proof combination' applies in case a modernisation of the categories is considered, with an **additional in-between LMT category**. In this case, it is **possible to include heavier products** compared to the 'base combination' that would otherwise not fit in the collection infrastructure for portable batteries. Therefore, all batteries in non-type approved wheeled vehicles and batteries in type approved L1e-L7e categories with an individual battery weight below 25 kg are recommended to be included. This effectively includes all e-bike and (larger) e-moped batteries as LMT batteries, while it excludes larger e-motorcycles (which will subsequently characterise as EV batteries). At the lower end, the threshold delineation from portable batteries can be made explicit by specifying wheeled toy batteries, not designed for use on the road, as portable batteries.

For the collection target, similar to the 'base option', 70% of AfC by 2025 and 75% of AfC by 2030 for both categories individually would correspond with the original ambition, with the alternative target basis reflecting the expected LMT waste battery volumes much more realistically. A revision clause and/or update procedure in this case might be wise to adapt the common methodology parameters and in case needed, the target level to the future development of the new 'fifth' category.

- The more ambitious 'optimising collection' combination is the same as the 'future proof combination' with **an additional differentiation of the collection target to portable rechargeable and primary batteries individually**. By disentangling them, the full benefit of potential of the AfC effort would be exploited by focusing the reporting and monitoring at the subcategory level. In the future, this would maximise transparency and focus on the environmental priorities related to portable rechargeable batteries with a relatively larger environmental footprint per battery than non-rechargeable batteries. At the moment, the actual collection rates for the two subcategories individually are not well-understood. When 'Option 3' is selected, the risk of cross-subsidising collection of rechargeable and LMT batteries by relatively collecting more 'less relevant' primary batteries would be removed. A constraint to this option will likely be increased monitoring and report efforts and possibly additional sorting costs. Assessment of additional costs and administrative burden are out of scope of this study.

In summary, reasoned solely from the collection perspective and by taking into account the various market scenarios evaluated in this report, the main recommendation **is a modernisation of the target basis to be converted from a POM based target to an AfC based target:** this study recommends Option 2 as 'future-proof' choice that would enable Option 3 with differentiated monitoring and reporting of primary versus rechargeable later. It would also form a basis for later deduction of non-collectable volumes, like batteries exported for reuse (with WEEE) and time to improve related monitoring and reporting procedures In case Option 2 is already selected in the current decision process, the benefit is that establishing more collection points with LMT, e-bike and e-moped dealers and improved handling and safety attention would not be postponed for this rapidly evolving category. A review clause might be needed to adjust of the collection target levels and the common methodology according to technical progress and to evaluate the impacts of option 3.

Regarding technical feasibility of developing a common methodology, JRC regards development of an AfC based common methodology feasible. In case of adopting an AfC based approach, the collection schemes in various Member States indicated willingness to timely develop the monitoring and reporting procedures as well as researches to substantiate the parameters for the necessary common methodology. The approach is anticipated to be more straightforward compared to the WEEE Generated methodology since historic market input is documented much better for batteries and there will be no need to connect the market inputs to trade statistics. Moreover, a much lower number of around 8 – 10 classes are foreseen for all LMT, primary and rechargeable batteries together, as well as the possibility to base the approach on 'simpler' lifespan distribution curve in this case.

Finally, with an **in-between** LMT category, there is an additional possibility to align other non-collection requirements to the distinctive character of LMT batteries, such as extending certain relevant sustainability, safety and information requirements, currently being proposed (solely) for portable and/or EV batteries. It is recommended to further analyse such potential benefits for the newly defined '**fifth'** category in the ongoing legislative process for other measures of the draft Battery Regulation.

1 Introduction

The Commission originally proposed in the December 2020 legislative proposal COM(2020) 798/3 for a new Regulation on batteries and waste batteries (European Commission, 2020b) that all batteries below 5 kg are considered portable (with some exceptions). Separate collection targets are proposed for portable batteries, except for portable batteries for Light Means of Transport (LMT). For the latter, the proposal envisages a review clause. It is anticipated that the on-going discussions in the Council and the European Parliament may re-focus the approach considering an alternative methodology based on Available for Collection (AfC). This study provides an assessment of various options for defining a possible category for LMT batteries and an initial quantification of battery volumes affected in case setting a separate collection target for batteries for light mobility would appear a meaningful alternative in the on-going legislative process.

1.1 Aim of the report

The current Battery Directive (European Commission, 2006b) classifies batteries in three groups of portable, automotive and industrial batteries. The newly proposed 2020 Battery Regulation adds electric vehicle (EV) batteries as a new 'fourth' category. With the fast rise of LMT batteries in e-bikes and recent new products like monowheels, hoverboards, e-scooters (called e-kick-scooters or e-steps in certain countries) plus larger e-mopeds (called e-scooters in certain countries) and e-motorcycles, this study investigates the possible need for a 'fifth category' of LMT batteries. Due to the technical development of lithium batteries, a significant amount of electrification of light vehicles is expected to appear as well. This trend will likely continue with Li-ion chemistries becoming increasingly cheaper, safer and more versatile. At this point, it is uncertain how many new LMT applications will appear in the market in the future and how this may affect the collection and recycling stages for portable and EV batteries in particular. With the battery market evolving rapidly, it seems appropriate to reflect on possible options. Moreover, within the current formulation in the legal proposal, there is effectively no collection target applicable for LMT batteries (yet), in contrast to the neighbouring portable and EV categories.

In the current proposal, LMT batteries are defined as:

> (9) 'light means of transport' means wheeled vehicles that have an electric motor of less than 750 watts, on which travellers are seated when the vehicle is moving and that can be powered by the electric motor alone or by a combination of motor and human power;

In addition, the current proposal includes the following option in Article 55:

> The Commission shall, by 31 December 2030, review the target laid down in paragraph 1(c) and, as part of that review consider the setting of a collection target for batteries powering light means of transport, in the light of the evolution of the market share, as a separate target or as part of a review of the target laid down in paragraph 1(c) and in Article 48(4). This review may also consider introducing a calculation methodology for the calculation of the separate collection rate with a view to reflecting the quantity of waste batteries available for collection. To that end, the Commission shall submit a report to the European Parliament and the Council on the outcome of the review accompanied, if appropriate, by a legislative proposal.

This present study first aims to provide the technical background and analysis of the quantities of batteries potentially involved both historically and in the future. For the LMT category, modernising the legal framework requires a closer investigation of the need to update definitions to provide future guidance on which batteries belong to which collection category. At this point in time, the study focuses on the need for legal clarity on the status of LMT batteries, first and foremost from a collection point of view. However, since the various categorisation options may affect other requirements, the study also briefly discusses in section 2.6.4 the possible consequences from a point of view of internal consistency in the current proposal.

Regardless of the choice for the collection target, a consistent LMT battery definition is nevertheless needed to specify them as unambiguously as possible as part of the portable and/or EV categories.

Therefore, the objectives of this JRC study are to support DG ENV in the co-decision negotiations on the new Regulation on batteries and waste batteries by providing a report:

1. Examining the options related to the definition of a separate category for Light Means of Transport (LMT) batteries and their implications;
2. Estimating the impact on targets of separate collection of portable batteries based on an alternative AfC methodology compared to the POM target, that is included in the December 2020 original Commission's legislative proposal;

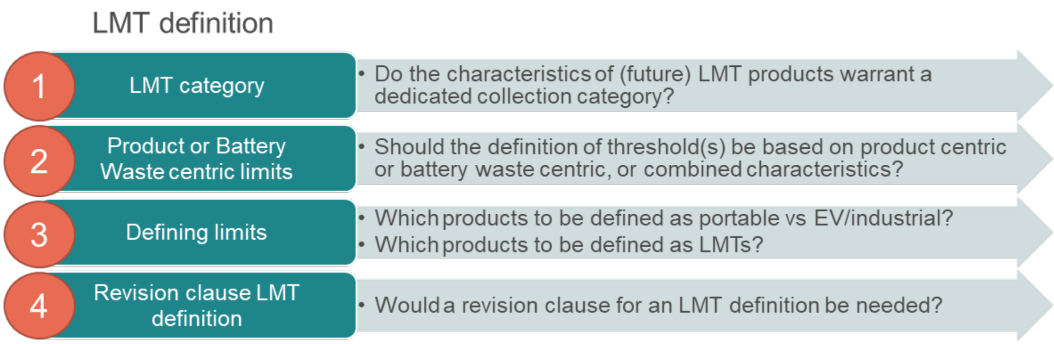
3. Providing a rough estimate of a possible targets for separate collection of batteries for LMT based on POM and AfC as far as data availability allows for this.

In case an alternative target is considered a viable option, JRC will be tasked to develop a new common methodology for the calculation and verification of data on separate collection of portable batteries, including separately for LMT, based on AfC. This second stage is planned in between September 2021 and June 2023 as a subsequent step following this study to enable implementation in the next years.

1.2 Approach – LMT definition

Due to the complexity of the topic and the large number of possible combinations of options in the decision process, a step-wise approach is constructed to extract the most relevant combinations of both the LMT category definition and collection rate alternatives. In total, 8 key questions are formulated in order to decide on the most relevant options and their combinations. The order of deciding on various options is particularly relevant for the effect of the (sub)categorisation of batteries on the need and structure of alternative collection targets. In simple terms, in case portable and LMT batteries remain in one category, the need for an alternative approach would be different compared to having an additional LMT category. Similarly, defining limits/threshold in case (sub)categorisation is applied subsequently, may affect the collection volumes and the need to adapt the collection target levels. For all combinations, various choices for both the categorisation and the collection target basis may result in different needs to include revision clauses and/or the need for updating secondary legislation. A description of the LMT category and future trends is provided at the beginning of Chapter 2, followed by answering the first key questions 1 to 4 of Figure 1.

Figure 1: Four key questions related to the LMT definition



1.3 Data analysis, research classification batteries

Parallel to this approach, various market scenarios to quantitatively assess the consequences of the most meaningful combinations are carried out. This market assessment is included in Chapter 3. This data analysis investigates the battery volumes involved when the approach is adapted to 'available for collection', similar to the "WEEE[1] generated approach" (Magalini et al., 2016). The dataset provided should compare the volumes of placed-on-market and corresponding AfC percentages for all portable batteries and separately for LMT batteries from 2010 until-2035 (and longer, where data availability and uncertainties allow). The dataset is based on latest available data from Eurostat (Eurostat, 2021), the impact assessment (European Commission, 2020c) and the JRC update of the H2020 ProSUM[2] and ORAMA[3] projects (Chancerel et al., 2016; Wagner et al., 2019) with later updates and EU battery amount information estimates published on RMIS[4] (Huisman et al., 2020).

Several classification approaches for batteries are available, depending on cell chemistry, hazardousness, chargeability, and area of application. However, for end-of-life research purposes, no classification existed to reflect raw material content and waste properties of batteries. In this context, the H2020 ProSUM project proposed a structured classification taking into account several aspects related to battery compositions (e.g. chemistries, applications, etc.). Based on expert knowledge on battery systems and the resources they contain, as well as an analysis of existing battery classifications, the ProSUM battery classification of electrochemical cells is further developed in the current report. All data for the quantitative analysis in this study is based on a

[1] WEEE: Waste from Electric and Electronic Equipment
[2] http://www.prosumproject.eu/
[3] https://orama-h2020.eu/
[4] https://rmis.jrc.ec.europa.eu/apps/bvc/#/

further update of the classification due to the constant emergence of new battery chemistry – application combinations, as visualised in Table 1. A full list of the battery keys in the last column is provided in Annex 1.

Table 1: Classification of batteries for research and waste quantification purposes.

Battery Directive (3)	Battery Regulation proposal (4 or 5)	Application family (7)	Application (>26)	Chemistry family (5)	Chemistries (11)	BATT keys (60)
Automotive	Automotive	Automotive (3x)	SLI	Lead Lithium	PbA, LMO, LFP	40,46,49
Industrial	Industrial	ESS - behind the meter (5x)	Home-BESS	Lithium	NMC, NCA, LFP, LMO, LCO	53,54,55,56,64
		ESS - front of the meter (10x)	Industrial, UPS, Machinery, large BESS, *maritime,* etc.	Lithium Nickel Lead Other	LCO, LFP, LMO, NMC, NiMH, PbA, NCA, Other	5,9,15,28,33 38,42,44,48,*69*
	EV	Traction (16x)	BEV, HEV, PHEV, MDV, HDV, e-motorcycles	Lithium Nickel	NMC, LMO, NCA, LFP, NiMH	13,14,25,26,27 37,47,50,51,57 58,60,61,62,63,68
Portable	LMT?	LMT (light means of transport) (4x)	monowheels, e-scooters, e-bikes, e-mopeds	Lithium Lead	LCO, LFP, LMO, NMC, PbA	24,65,66,67
	Portable (or split?)	Portable primary (3x)	Electronics and all general use primary	Alkaline Lithium Other	Alkaline (incl. Zn + Mn), Li-primary, other	43,45,59
		Portable rechargeable (19x)	Portable PC, cell-phones, cameras/ games, tablets, cordless tools, others portable	Lithium Nickel Lead Other	LCO, LMO, NMC, NiMH, NiCd, LFP, PbA	1,2,3,6,7,10,11 18,19,20,21,22,23 31,32,34,35,36,39

Sources: Chancerel et al. (2016); Wagner et al.(2019), Huisman et al. (2020)

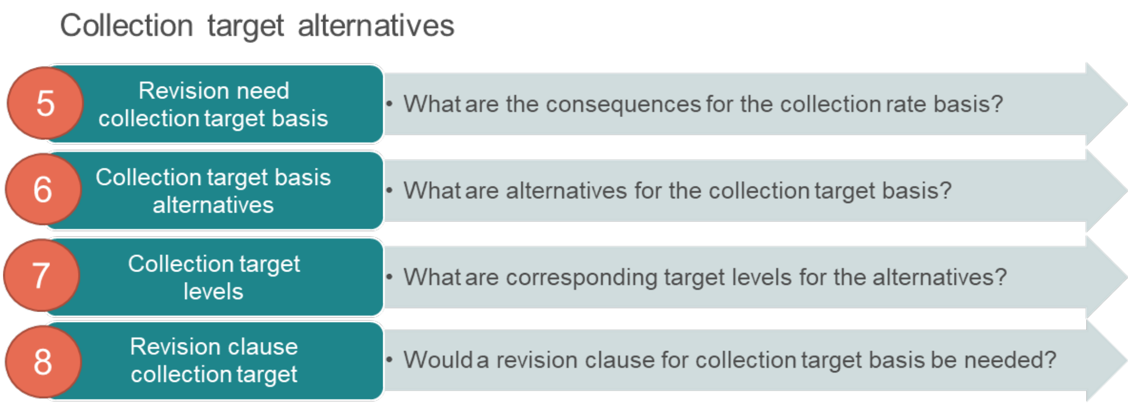
Table 1 forms the basic structure for the computation of various collection target correspondences, amongst others, the inclusion or split of LMT batteries to portable and EV batteries. The classification forms the analytical structure to describe all compositions, lifetimes, weights and other parameters for the dataset to be computed for various future market scenarios affecting expected waste volumes in the future.

The calculation approach includes using a different range of reference years and different scenarios as illustrated in Section 3.1. Moreover, uncertainty of relevant parameters is addressed in the form of a sensitivity analysis presented in Section 3.4. The provided dataset is designed flexibly to determine the consequences of differentiation in various subsets, like e.g. into primary vs rechargeable batteries, Li-ion based versus non-Li-ion based, etc. For LMT, the data collected should be able to support the assessment of a possible level of a separate collection target.

1.4 Collection target alternatives

The results from the quantification form the basis for answering the below questions 5-8 in Figure 2 related to reviewing options for the definition of the collection target in Chapter 4.

Figure 2: Four key questions related to the collection target alternatives



Similar to Chapter 2, again 4 questions are formulated depending on the results of the LMT categorisation of Chapter 2. This influences the formulation of the collection target alternatives as both the need for a revised target **basis** and related target **levels** depend on the different volumes at stake in relation to the categorisation options from Chapter 2.

1.5 Technical consultation of key stakeholders

To support the work, several targeted consultations of stakeholders were organised to gather the necessary market information and feedback on the feasibility of various options. Two workshops were held on March 19 and May 19 2021 to gather necessary documentations plus feedback on the technical feasibility and consequences of various options. The data gathering exercise focused on key representatives of EU branch organisations of producers, recyclers and producer responsibility organisations (PRO's) to acquire technical information on battery sizes, capacities, past and future market trends for old and new products to be expected as well as data related to battery collection experiences in the EU. In the consultation, various options to improve information are discussed, including more reliable measuring of hoarding, battery residence time[5] in households and businesses, measuring of batteries in municipal solid waste and WEEE as well as best practices in monitoring collection, surveys and collection campaigns.

Since the expected market evolution of LMT products can significantly affect the characteristics of the collection categories, the consultations specifically focused on the characteristics of this group of products, currently dominated by e-bikes. Dependent on the choices to be made, the feasibility of a common methodology for the collection target will rely on the inclusion of LMT battery volumes into existing or new collection infrastructures for (portable) and EV batteries.

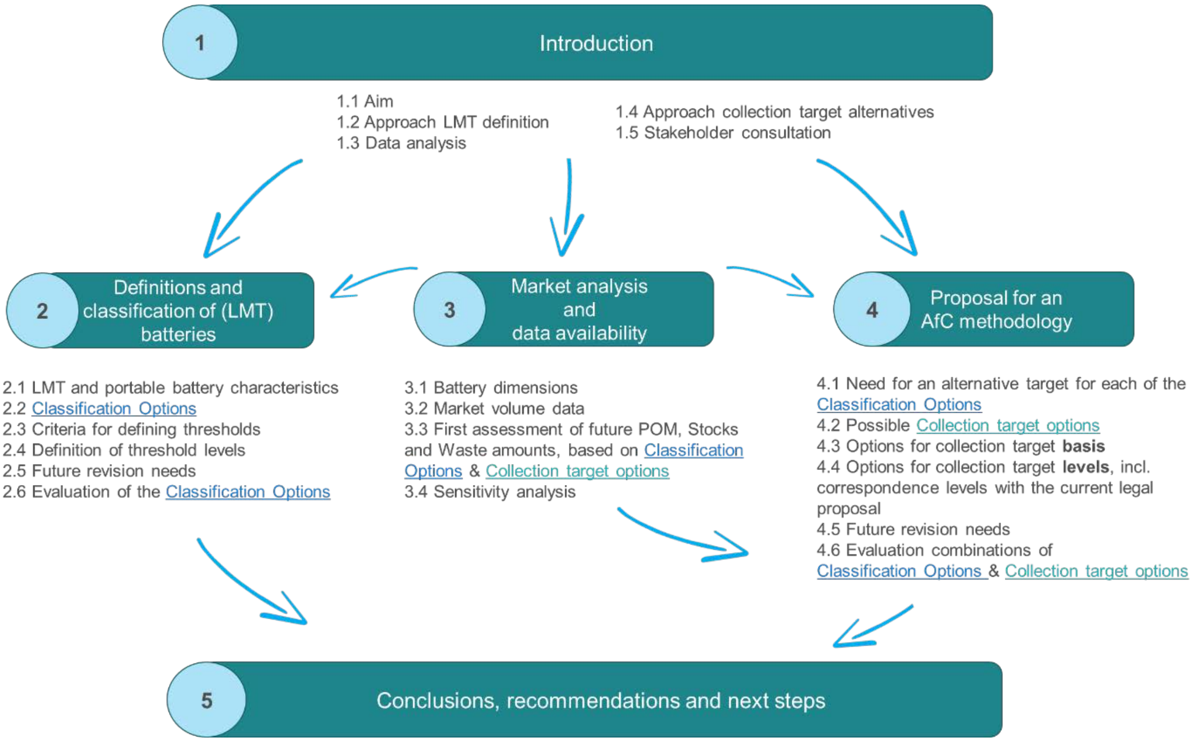
Therefore, besides these two large meetings, many bilateral interactions were held with the stakeholders to directly collect necessary technical evidences. An overview of all feedback collected is provided in Annex 2 and Annex 3.

[5] "The residence time is the total time batteries remain in (subsequent first, second or third) use before being discarded as waste or shipped outside the EU territory which is used as the system border" (Di Persio et al., 2020)

1.6 Readers guide

Below Figure 3 provides and overview of the thinking steps of Section 1.2, 1.3 and 1.4 and where specific information can be found in the next chapters.

Figure 3: Reader's guide



2 Definitions and classification of (LMT) batteries

Based on products currently available on the markets and the expected evolution of Li-ion battery technology, LMT batteries can belong to different categories being either portable batteries, EV batteries or become a category on its own. In case such a new 'fifth' category is defined, as well as in case it is not, unambiguous definitions are needed to determine which products are included and excluded from the respective categories that will ideally apply similarly across the EU. In this chapter, following a short analysis of LMT battery characteristics (Section 2.1), 4 key questions are formulated and subsequently answered related to:

i. The need for a separate LMT category (Section 2.2);
ii. The basis for including or excluding products in the LMT category (or with portable versus EV batteries), e.g. related to function, weight and/or capacity; (Section 2.3);
iii. The choice for threshold levels (Section 2.4) and finally;
iv. Whether a revision clause and/or update related to technical and scientific progress would be necessary (Section 2.5).

The advantages and disadvantages of various option combinations are discussed in Section 2.6. The consequences for the current definitions in the legislative proposal for the most logic combinations is presented in Section 2.6.

2.1 LMT battery characteristics

— What are the characteristics of (future) LMT products?

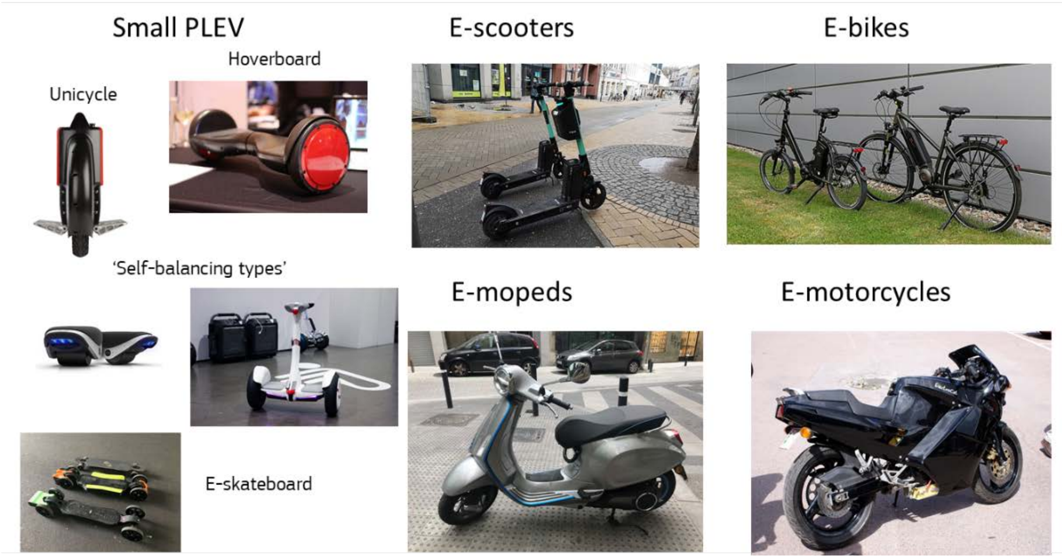
E-bikes are the far majority of the LMT products placed on market by weight. From roughly 20 million sales of bicycles in the EU27+3, approximately 25% are already electric in 2020 (CONEBI, 2021b). In some countries, significant market introduction occurred a number of years ago, with relevant numbers of batteries reaching the end-of-life stage already. In other markets, this occurs later. As a result, different collection strategies are found in different Member States. Some countries are collecting e-bike batteries together with portable batteries like Austria. In other countries, PRO's have organised a dedicated and often voluntary return channel like Belgium, France, Greece or are in the process of organising this in the near future, like the United Kingdom (CONEBI, 2021c; COREPILE, 2019). In some countries with multiple battery PRO's, either portable battery or EV/Industrial battery PROs are eligible to collect waste batteries. In Germany, the collection channel is adapted to deal safely with larger pack sizes by providing dedicated steel collection barrels and safe handling instructions to adapt to LMT battery characteristics (Wettendorf, 2020). In the Netherlands, a dedicated PRO is created specifically responsible for e-bike batteries with more countries following this approach soon (EUCOBAT, 2021).

The difficulties to classify LMT batteries relate to a number of issues:

1. As a relatively new group of products, new market introductions and future innovations are expected. Recently, many new products are introduced in significant quantities like monowheels, hoverboards and e-scooters. Both e-scooters and e-mopeds are introduced in large cities in sharing schemes in significant quantities. These products are more and more complementing or replacing public transport modes in cities.
2. Several LMT products, in particular e-bikes up to 25 km/h are non-type-approved and many product sub-types with similar compositions exist simultaneously in both type-approved and non-type approved classes of the L-category in the type approval the Regulation (EU) No 168/2013, like for example batteries in so-called EPAC25[6] (e-bikes < 25 km/h and < 250W continuous power) versus the same batteries in EPAC45 (e-bikes <45 km/h and <1 kW). Reversely, products in the same category are identified as well with rather different battery dimensions.
3. Products with multiple batteries with a much higher total capacity are found in 'heavier' categories, but with individual battery dimensions corresponding to those in lower classes. Here, it is not unlikely that modular batteries will be introduced in the future, that may fit in several applications, potentially even including non-light mobility applications like residential energy storage, tools or machinery equipment. Consequently, this may further 'blur' current classifications and lead to overlaps and legal uncertainty about the responsibilities for collection and recycling.
4. Both very small to very large battery pack sizes are identified in LMT products ranging from the low end with small wheeled toys to heavy e-motorcycle batteries with over 20 kWh ones with a potential weight of a 100 kg.

[6] EPAC: Electrically Pedal Assisted Cycles

Figure 4: Glossary of LMT products



Based on the feasibility study on sustainable batteries for LMT products (Moll et al., 2019), and a range of feedbacks from CONEBI[7], LEVA-EU[8] and ACEM[9] (ACEM, 2021; CONEBI, 2021b; CONEBI, 2021c; LEVA-EU, 2021a; LEVA-EU, 2021b), the following overview table is constructed. The table represents both type-approved and non-type approved products, the typical collection channel, battery capacity, weight, vehicle range and power rating. In Table 2, the column titled "This study" reports the name of the batteries categories as used in the following chapters of this report, forming the basis for the number of units POM following various market assessments. Note that the term 'small PLEVs' (personal light electric vehicles) is chosen to aggregate all monowheels, uniwheels, e-skateboards, hoverboards, self-balancing vehicles, with or without a saddle, but excluding the similarly small e-scooters, which are regarded separately due to their high number of sales.

The table on the next page is created to support decisions on the LMT categorisation. Such a choice and the corresponding definition ideally should be least subjective to partial interpretations in the Regulation when drawn for instance on the basis of product classes like the L-subcategories or speed, range or power in above table. Equally, the definition of thresholds should aim to group all batteries with similar collection, handling and recycling characteristics in case a choice would be made on the basis of battery dimensions like capacity and/ or weight.

The table illustrates already that the current definition 9 on 'light means of transport' is troublesome in its reference to motors 'of less than 750 watts'. It is found to be problematic in referencing to 'on which travellers are seated' with a significant amount of smaller LMT products without a seat. Both types of parameters effectively discriminate between products with comparable battery characteristics. Thus, an alternative choice is recommended to provide sufficient legal clarity for the future and importantly from a collection point of view, to bundle together all batteries with similar dimensions and uses.

Whatever decision is considered, it should remain consistent in case new product types are introduced. Moreover, consistency is needed in relation to requirements for other battery categories. In particular for the split between portable and industrial batteries, currently set at 5 kg of battery weight. Table 2 shows, this would effectively cut the large amount of e-bike batteries, with a typical weight range up to 6.5 kg, in two parts.

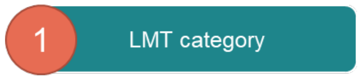
Furthermore, other requirements newly proposed for EV batteries, should also be consistent with decisions to be made for LMT. In this respect, Table 2 shows that typical battery capacities for instance found for smaller 2-wheeled e-mopeds are roughly equivalent to the typical capacities of (mild) HEV[10] batteries, whereas the larger e-mopeds and e-motorcycles are more corresponding with typical battery capacities found in PHEVs.

[7] CONEBI, Confederation of the European Bicycle Industry, https://www.conebi.eu/
[8] LEVA-EU, European Light Electric Vehicle Association, https://leva-eu.com/
[9] ACEM, European Association of Motorcycle Manufacturers, https://www.acem.eu/
[10] (P)HEV: (Plug-in) Hybrid Electric Vehicles

Table 2: LMT characterisation

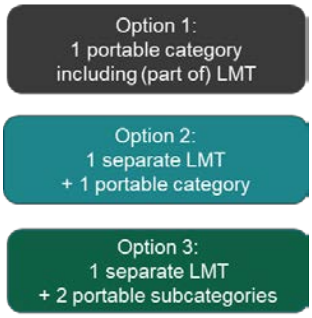
Code	Category	Sub-category	Category name	This study	Typical collection channel	Typical capacity (kWh)	Typical weight (kg)	Typical Range (km)	Power (contin. rated, kW)
Non-type approved									
	Mono-wheel, hover-board, e-skateboard, unicycle, self-balancing vehicle, etc.		**Small PLEV (65)**		Sport shops Bicycle + scooter dealers	0.15 – 1.1	0.8 – 3.0	25	0.25-1.8
	E-scooter, e-step, kick scooter		**E-scooter (66)**			0.15 - 1.3	0.8 – 4.2	32	0.25-0.5
	E-bike		EPAC25 (<250W, classified as conventional e-bikes)	**E-bike (24)**		0.3 – 1.0	2.0 – 6.5	60	<0.25
Type approved									
L1e	Light two-wheel powered vehicle	L1e-A	Powered cycle (E-bike < 25 km/h)	**E-bike** with throttle	Bicycle + scooter dealers	0.5 – 1.7	2.0 – 6.5	60	0.25 - 1
		L1e-B	Two-wheel moped, e-scooter w. saddle + speed pedelecs (<45 km/h)	**E-moped 2-wheels (67)** Incl. EPAC45		E-scooter w. saddle 0.15–1,3 EPAC45: 0.3-1.0 e-moped: 1.4-4.8	E-scooter w. saddle 0.8-3.0 EPAC45: 2.0-6.5 E-moped45: 8-20	32 - 80	<4
L2e	Three-wheel moped	L2e-P	Three-wheel moped for passenger transport	**E-moped 3-wheels**		1.4 - 4.8 (some products can have multiple battery packs)	8 - 25+	80	
		L2e-U	Three-wheel moped for utility purposes						
L3e	Two-wheel motorcycle	L3e-A1	Low-performance motorcycle	Incl. e-mopeds < 70 kmh	Scooter + motorcycle dealers		8 - 25+		
		L3e-A2	Medium-performance motorcycle	**E-motorcycle (68)**		7 – 21 (some products can have multiple battery packs)	25 - 80	180	>4
		L3e-A3	High-performance motorcycle						
		L3e-AxE	Enduro motorcycles						
		L3e-AxT	Trial motorcycles						
L4e	Two-wheel motor-cycle with side-car	L4e	Two-wheel motor-cycle w. side-car						
L5e	Powered tricycle	L5e-A	Tricycle	**E-tricycle**	Tricycle+ quadricycle dealers				
		L5e-B	Commercial tricycle						
L6e	Light quadricycle	L6e	Light quadricycle			8 - 25	30 - 100	120	>4
L7e	Heavy quadricycle	L7e	Heavy quadricycle	**E-quadricycle**					

2.2 Classification of LMT and portable batteries



— Do the characteristics of (future) LMT products warrant a dedicated collection category?

There are three main options identified for the categorization of LMT and portable batteries in the scope of this study:



1. No additional separate LMT category, one portable category (partly) including (lighter weighted) LMT products (Option 1).
2. One separate LMT category plus one portable category (Option 2).
3. A separate LMT category and two portable subcategories for rechargeable and non-rechargeable portable batteries (Option 3).

The reasoning behind adding a separate category is that it may correspond better with the anticipated collection channels and unique properties of LMT batteries allowing differentiation when creating a separate collection category and the possibility for more transparency and improved monitoring of collection performance.

Against that background, key questions are:

1. Do LMT batteries have unique properties in comparison to both EV and portable batteries, considering their weight, composition properties, handling characteristics and lifespans?
2. Is there a significant volume expected?
3. How does selecting a separate category potentially affect other legal requirements?

Responses are:

1. On average, LMT batteries are significantly heavier than portable batteries and, for the smaller sized properties, significantly lighter than EV batteries in the M, N and O classes of the type-approval legislation (EU Directive 2007/46/EC).
   a. In terms of composition, the majority of these batteries are based on cylindrical cells in comparison to (still) a high use of pouch cells in the case of portable electronic products.
   b. It is expected that higher capacities and energy densities will appear in the future to either boost range and/or improve the portability of LMT products.
   c. An important difference raised by stakeholders is that the larger packs require different safety and handling safeguards than smaller portable ones (COREPILE, 2019; Wettendorf, 2020; Mobius, 2020). For portable batteries, primary batteries act as a buffer for smaller rechargeable batteries mixed in, providing more intrinsic safety. This does not apply in case of dedicated collection bins for LMT batteries. Alike many pouch cells in larger electronics items, in mechanical WEEE recycling processes, the larger LMT packs are equally not desired in traditional shredding stages.
   d. Furthermore, many of the traditional collection boxes may be too small for LMT products. From a consumer's point of view, the common LMT sales channels, besides online sales, are sport-shops, bicycle and scooters dealers which form a distinct collection channel from batteries in electronics and tools, for which PRO's ideally should organise take-back efforts.
   e. Especially for larger LMT batteries: higher lifespans are certainly the cases for e-bikes, e-mopeds and e-motorcycles in comparison to portable batteries.
   f. Specific concerns are highlighted by stakeholders related to possible second life options and in particular, for rapidly emerging remanufacturing of relatively expensive batteries. On one hand, non-professional repair and remanufacturing practices may create fire-safety issues and warranty concerns. On the other hand, professional remanufacturing activities can prolong life and retain economic and environmental value in the future. Potentially, this can be organised better in case a dedicated collection channel is created.
2. Currently, e-bikes are the bulk in weight, with e-moped batteries growing rapidly and in the future the relatively large size of e-motorcycle batteries as well, in case included. Together, all LMT batteries will become a significant collection volume. The next Chapter 3 shows that the total volume can potentially be of the same order of magnitude in tons compared to portable rechargeable batteries.
3. As such, the review of other requirements in the proposed Battery regulation is out of scope of this study. In case LMT is introduced as an in-between category however, there are potential consequences

that cannot be ignored: An in-between category creates the possibility to apply some of the relevant requirements similar to portable batteries like collection and durability requirements, and other requirements more similar to EVs like for instance information and battery passport aspects, as well as repair and remanufacturing aspect like a 'repair friendly BMS' requirement in the future. This will be further elaborated upon in Section 2.6.4.

Important to highlight is that in case there is not LMT category defined, there would be a need to divide the LMT products between portable versus EV batteries, possibly leading to defining a **single** lower limit compared to **two** limits to be defined for the lower and upper boundary in case an **in-between** category is considered.

2.3 Product-based or waste battery-based limits

— Should the definition of threshold(s) be based on product function, battery waste dimensions or combined characteristics?

As a second step in the decision process, three main options exist for the **basis** of defining limits for either assigning the LMT products to the portable and/or EV categories, or for defining a new LMT category:

A. Product/ device approach, based on the definitions of the L-category and additional function based definition for non-type approved **products**, or;
B. Battery waste approach, based on **battery** dimensions, or;
C. A combination of above A & B.

Figure 5: Options for the basis of defining category limits

Whatever choice is made, the result ideally maximises the grouping of batteries with similar characteristics into the desired collection channel. As illustrated in Table 2, this is not trivial due to many overlapping characteristics.

An important consideration in this respect is that the proposed Regulation aims at the **battery** (waste) and not the **device** that is being powered. The latter is potentially subject to other legislation like the WEEE, ELV[11] and Machinery Directives (European Commission, 2012; European Commission, 2000; European Commission, 2006a), with even battery removal provisions as part of separate treatment requirements like for instance in the WEEE Directive. Moreover, collection, handling and recycling properties are related to the **battery** and not the carrier product. On the other hand, from a point of providing legal clarity, the advantage of the type-approval legislation is that this should in principle be interpreted uniformly across the EU.

The subsequent definition needs from the combined choices from step 1 (previous) section and the step 2 in this section are displayed below. Again, in the case of **no separate LMT category**, only **one threshold** needs to be defined. In case of a separate **LMT category, a lower and an upper limit** are required.

[11] ELV: End-of-Life Vehicles

2.4 Defining limit values

2.4.1 In the case of no separate LMT category

— Which products to be defined as portable vs EV?

Option A: In case of defining a split based on product functionalities, a range of possibilities exist ranging from including all LMT products with portable batteries versus including them with EV batteries and every level in between as illustrated in Table 3.

Table 3: Splitting LMT products as portable or EV batteries based on product function

With portable batteries	With EV batteries
None of the light LMT products	All small PLEV and other non-type approved LMT products
Small PLEV, monowheels/e-scooters	All e-bikes + larger
Non-type approved, incl. e-bikes < 25 km/h	Type approved (L1e and higher)
All non-type approved + L1e-A powered cycles	**L1e-B and higher**
All non-type approved + L1e-A + L1eB 2-wheeled e-mopeds < 45 km/h + speed-pedelecs	L2e and higher
All non-type approved + L1e + L3e-A1 e-mopeds < 70 km/h + low performance motorcycles	L2e, L3e-A2 and higher
All non-type approved + L1e + L3e-A1 + L2e 3-wheeled mopeds + cargo bikes	L3e-A2 and higher
All type and non-type approved vehicles in the L-class	None

* **In bold**: most logic/ preferred choice

Based on recommendations from the PRO's related to desired maximum sizes of batteries in the portable category (around 8 kg), it would be most logic, from all possible combinations, to group all non-type approved plus L1e-A bicycles with the portable ones. Ideally, also e-bikes < 45 km/h would be included, however, from a function definition, these are difficult to be distinguished from e-mopeds with larger battery packs in the same L1e-B category.

Option B: In case of defining a split based on battery dimensions, again a similar range of possibilities exist as illustrated below in Table 4: It is assumed here for batteries POM now in these products, based on a gravimetric energy density of 250Wh/ kg, that 1 kWh roughly represents 4 a 5 kg. This is expected to improve in the coming years towards 330 Wh/ kg or 3 kg of battery per kWh. This technical development as such already illustrates that battery weight is a more future-proof parameter over battery capacity for battery categorisation.

Table 4: Splitting LMT products as portable or EV batteries based on battery dimensions

With portable batteries	With EV batteries
< 0.5 kg (or < 0.1 kWh)	> 0.5 kg (or > 0.1 kWh)
< 1 kg (or < 0.25 kWh)	> 1 kg (or > 0.25 kWh)
< 2 kg (or < 0.5 kWh)	> 2 kg (or > 0.5 kWh)
< 5 kg (or < 1.25 kWh)	> 5 kg (or > 1.25 kWh)
< 8 kg (or < 2 kWh)	**> 8 kg (or > 2 kWh)**
< 12 kg (or < 3 kWh)	> 12 kg (or > 3 kWh)
< 20 kg (or < 5 kWh)	> 20 kg (or > 5 kWh)
< 25 kg (or < 6 kWh)	> 25 kg (or > 6 kWh)

* **In bold**: most logic/ preferred choice

Based on recommendations from PRO's related to collection and handling characteristics, combined with observing the upper weight limit of e-bikes, a limit around 7.5 kg to 8 kg of battery would represent a logic and recommended split to group most types of e-bikes from larger LMT batteries. Excluded as criteria are range and power since these criteria would lead to various ambiguities due to not relating directly to battery dimensions.

Option C: In case the two options in Table 3 and Table 4 are combined, as an example, the definition can be formulated as: Portable batteries include all batteries in non-type approved vehicle including those in the L-category with a weight below 8 kg.

This option is benefitting of the combination of the two above approaches in order to optimise the grouping of batteries with similar characteristics from both the dimensional and functional point of view. In simple words, all batteries from e-bikes, regardless their speed and type approval, plus occasional smaller batteries in type approved vehicles, as well as some slightly heavier ones in **non-type approved vehicles** would be included. The net result groups batteries with similar dimension and approximates best the desired collection channels and probably matches most 'naturally' with consumers' expectations for these batteries.

Option 2:
1 separate LMT
+ 1 portable category

Option 3:
1 separate LMT
+ 2 portable subcategories

3 Defining limits

2.4.2 In the case of a separate LMT category:

— Which products to be defined as LMT?

Option A: In case of defining the necessary two thresholds based on product functionalities, a range of possibilities exist ranging from including all LMT products with portable batteries versus including them with EV batteries and every level in between as illustrated in Table 5.

Table 5: Setting lower and upper thresholds for LMT products as a separate category based on product function

Lower limit	
With portable batteries	**As LMT batteries**
All toy-alike 'vehicles' typically designed for house and garden use	**All small PLEV, monowheels and other non-type approved LMT products and larger designed for use on the road**
Idem + all small PLEV, monowheels/e-scooters	All e-bikes + larger
All non-type approved, incl. e-bikes < 25 km/h	All type approved (L1e and higher)
Upper limit	
As LMT batteries	**With EV batteries**
All non-type approved, incl. e-bikes < 25 km/h	L1e-A and higher
Idem + L1e-A (all e-bikes, excl. EPAC 45 km.h)	L1e-B and higher
Idem + L1e + L3e-A1 (incl. all bikes and e-mopeds)	**L2e, L3e-A2 and higher**
Idem + L2e	L3e and higher
Idem + L1e, L2e, L3e-A1	L3e-A2 and higher
All type and non-type approved vehicles in the L-class	None

* **In bold**: most logic/ preferred choice

Based on all stakeholder feedback related to desired size of batteries in case of a separate LMT category, it is possibly attractive to include much heavier products in a dedicated collection channel designed to handle larger battery packs safely. Recommended is to exclude toy-like products at the lower end that are not designed for use on roads and sidewalks. Regarding the upper limit, in this case all mopeds can ideally be included, which are specified under the L1e-B category for those with a speed up to 45 km/h as well as those in L3e-A1 for those with a speed up to 70 km/h since they are often rather identical products. This would automatically include e-bikes < 45 km/h as well in the LMT category that are very similar to the non-type approved e-bikes.

Option B: In case of defining both thresholds based on battery dimensions, again a similar range of possibilities exist as illustrated below in Table 6: Again it is assumed here for batteries POM that 1 kWh currently roughly represents 4 a 5 kg, further improving towards 3 kg of battery per kWh.

Table 6: Setting lower and upper thresholds for LMT products based on battery dimensions

Lower limit	
With portable batteries	**As LMT batteries**
< 0.5 kg (or < 0.1 kWh)	**> 0.5 kg (or > 0.1 kWh)**
< 1 kg (or < 0.25 kWh)	> 1 kg (or > 0.25 kWh)
< 2 kg (or < 0.5 kWh)	> 2 kg (or > 0.5 kWh)
< 5 kg (or < 1.25 kWh)	> 5 kg (or > 1.25 kWh)
< 8 kg (or < 2 kWh)	> 8 kg (or > 2 kWh)
Upper limit	
As LMT batteries	**With EV batteries**
< 12 kg (or < 3 kWh)	> 12 kg (or > 3 kWh)
< 20 kg (or < 5 kWh)	> 20 kg (or > 5 kWh)
< 25 kg (or < 6 kWh)	**> 25 kg (or > 6 kWh)**
<100 kg (or 25 kWh)	> 100 kg (or > 25 kWh)

* **In bold**: most logical/ preferred choice

Based on all stakeholder feedback and the typical weights and capacities of the batteries, involved, a lower limit of 0.5 kg would exclude most toy alike products and an upper limit of 20 to 25 kg would represent the most logical split that includes the majority of e-mopeds in the LMT category, leaving larger e-motorcycle batteries with the EV category. Again, excluded are range and power as criteria since these criteria would lead to various ambiguities and not necessarily provide clarity from a waste collection perspective.

Option C: In case the two options in Table 5 and Table 6 are combined, as an example, the definition can contain specific combined phrases like: i) LMT batteries are excluding toys equipped with a battery as specified in the Toy Safety Directive 2009/48/EC **and** ii) including all batteries in non-type approved wheeled vehicles plus iii) batteries in type approved L1e-L7e categories with an individual battery weight below 25 kg (and/ or 5 kWh). Combined phrases like this would exclude batteries from vehicles that are in N, M and O categories from an LMT category and effectively classify these as EV batteries. For a more specific formulation, see Section 2.6.2.

The advantage of this option is benefitting of the combination of the two above approaches to optimise the grouping of batteries with similar characteristics from both the dimensional point of view as well as occasional smaller or lighter batteries in certain products. For the lower limit, specifying a value is not deemed necessary since a functional split between toys and small PLEV designed for road use would suffice. In simple words, in this option, the bulk of batteries from e-bikes **and e-mopeds plus all lighter non-type approved vehicles with similar weights** would be included, regardless of their speed or power. From a consumer perspective, the net result aligns closest with all LMT batteries typically sold via sport shops, e-bike, e-scooter and e-moped dealers.

4 Revision clause LMT

2.5 Potential need for revision

— Is a revision clause for LMT definition needed in the future?

Dependent on the choices made above, different needs for a necessary revision may be needed for the battery categorisation choices, dependent on the responses to the following questions:

1. Will the LMT product characteristics evolve over time?
2. Could there be other legal requirements assigned to the LMT category in the future?
3. Are there legislative changes expected in adjacent legislation?
4. Are there relevant technical and scientific progress expectations/ uncertainties remaining?

Responses to these questions are:

1. Technical developments, new innovations and constantly improving energy density, battery handling changes alike battery swapping between products, energy storage etc., will surely affect future L-classes and/or key parameters like battery capacity. In simple terms, based on the stakeholder's feedback, there remains significant uncertainty how the size and nature of the LMT products will look like in the future. Hence, a revision clause in recommended for both the option 1 versus Option 2 and 3.
2. Future additional requirements related to sustainability/ durability/ remanufacturing and repair as well as battery passport information developments may affect future needs to adapt requirement for these products. A revision clause here, would allow more flexibility for policy decisions in the medium term without having to revise the core legal text of the proposed Regulation. This will be further made explicit in Section 2.6.4
3. Future revisions of the type approval classes of Regulation 168/2013 (European Union, 2013) and the ELV Directive revisions may lead to a need to re-align with the proposed Battery Regulation. The same counts for any legal changes in the Machinery Directive and Toy Safety Directive (European Commission, 2006a; European Commission, 2009).
4. With higher capacities and completely new product types expected to appear, flexibility and possibly additional products or waste related standards may be developed in the future, which can be easier to handle in case LMT batteries are defined as a separate category.

2.6 Evaluation of LMT classification options

In this section, the options for classifying LMT batteries are evaluated by highlighting the main advantages and disadvantages for the three proposed classification options.

2.6.1 Option 1: No separate LMT category

Table 7 provides an overview of advantages and disadvantages of the options of defining limits in case of no addition of a separate LMT category. Even in the case of not adding an additional category, still clarity is need on how to regard LMT batteries related to the definition 9 as well as for future clarity when more and more new products will be introduced to the market. In case lighter LMT batteries are grouped with portable batteries, it is recommended to select option C: that is to classify all batteries in non-type approved vehicles including those in the L-category with a weight **below 8 kg**. This choice provides the most legal clarity and effectively groups all e-bike batteries and smaller with portable batteries on one hand and leave e-moped batteries and larger LMT batteries to the EV category on the other hand. A weight based limit in conjunction with the functionality definition would prevent a certain amount of batteries from e-bikes with very similar characteristics for the carrier product and a capacity slightly above 2 kWh to fall into the EV category.

Table 7: Advantages and disadvantages of defining limits in case of no separate LMT collection category

Option	Pro	Con
Option 1: 1 portable category including (part of) LMT	Similar to current Battery Directive	**LMT products still to be defined as either portable vs EV or industrial batteries,** Less possibilities to adapt collection levels according to market dynamics, less possibilities to align category specific other requirements related to durability, safety, remanufacturing, etc. **Larger LMT batteries do require different handling at collection points and further logistics for safety reasons.**
Option A: Product centric	**Simple** and unambiguous from a product definition point of view: follows the 1:1 the classification of Regulation 168/2013	The Regulation aims at the battery (waste), not the product potentially subject to other legislation (battery removal provisions in e.g. the WEEE, ELV or Machinery Directives). The collection, handling and recycling properties are related to the battery, not the product. New products with new functionalities may appear.
Option B: Battery waste centric	Simple, more oriented towards the **battery dimensions and waste handling properties**. Weight is a more favorable option than capacity.	Batteries in the same L-category may be subject to different collection channels. Energy density is likely going up, for heavier products more range is desired. 'Capacity' needs to be defined.
Option C: Combination of A & B	All batteries with similar properties are destined to their 'natural' collection channel designated categories (portable/EV).	**The definition will be more elaborate,** however a functional description would be required for any option.

Nr	Defining a corresponding split between portable and EV/ Industrial		
	Option A: Product centric	Option B: Battery waste centric	Option C: Combination of A & B
i)	Include all non-type approved products: monowheels, e-scooters and e-bikes	**< 8 kg** (and/or 2 kWh)	Portable includes any battery in all non-type approved products: monowheels, e-scooters and e-bikes, as well as in L1eA, plus all batteries in L1eB and higher with a weight below ***8*** kg (and or **2** kWh).
ii)	Idem as i) + type approved L1eA	< 12 kg (and/or 3 kWh)	
iii)	Idem as ii) + L1e, L2e and L3eA1	< 25 kg (and/or 6 kWh)	

In case this combination option 1C is considered, the weight based threshold distinguishing portable from industrial batteries, may be aligned with the suggested LMT limit of 8 kg. In addition, an extra line may be added in the portable battery definition 8 to include the lower end of the LMT products as portable batteries. Obviously, Definition 9 on 'light means of transport' can be deleted for this option. Consequently, the definition of EV battery needs to be updated in order to include the higher end of the LMT products. Due to explicit mentioning of the L-category as in Regulation 168/2013, it is recommended to adapt the definition of EV batteries referring to the type approval Directive 2007/46/EC as well to provide maximum legal clarity by referring to the M, N and O categories. In case this option is considered, the changes to the Regulation proposal can be reformulated like this (suggested changes in red)

Definition (8): 'portable battery' means any battery that:

– is sealed;

– weighs below **8** kg;

– is not designed for industrial purposes; and

– is neither an electric vehicle battery, nor an automotive battery;

- can be powered by the electric motor alone or by a combination of motor and human power and batteries in vehicles, including all batteries of the **L1eA** category, and including batteries in vehicles of the categories **L1eB, L2e - L7e** as specified in Regulation (EU) No 168/2013) **and a weight below 8 kg.**

~~Definition (9): 'light means of transport' means wheeled vehicles that have an electric motor of less than 750 watts, on which travellers are seated when the vehicle is moving and that can be powered by the electric motor alone or by a combination of motor and human power;~~

Definition (12): 'electric vehicle battery' means any battery specifically designed to provide traction to a vehicle of category **L1eB, L2e – L7e** in the meaning of Regulation (EU) No 168/2013 **and a weight above 8 kg**, or to a vehicle of categories M, N or O in the meaning of EU Directive 2007/46/EC.

2.6.2 Option 2: A new separate LMT category

Table 8 provides an overview of advantages and disadvantages of the options of defining limits in case of adding a separate LMT category. Alike option 1, again it is recommended to consider option C for defining both limits: That is to group all batteries ranging from small PLEV and e-scooters as non-type approved vehicles to all types of e-bikes and e-mopeds as well as some of the light–weight e-motorcycles and faster e-mopeds that resemble closely in terms of battery size to bulk of e-mopeds by including an upper weight limit of 25 kg. This combined choice provides the most legal clarity and effectively groups all LMT products besides e-bike batteries, including e-moped batteries, leaving all large e-motorcycle batteries with the EV category. Additionally, from a consumer perspective, the most 'logical' upper limit lies around 25 kg and about 5 to 6 kWh where batteries with a capacity above that are generally intended for higher speeds or for larger cargo hauling vehicles originating from different sales channels than moped and bicycle dealers.

Table 8: Advantages and disadvantages of defining limits in case of a separate LMT collection category

Nr	Option	Pro	Con
	Option 2: 1 separate LMT + 1 portable category	With an **in-between category**, more possibilities to adapt collection levels according to market dynamics to align category specific other requirements related to durability, safety, remanufacturing, etc. **From a safety and handling point of view, there is a need to account for larger batteries with higher risks.**	**LMT products still to be defined with a clear lower limit to distinguish from portable and an upper limit for EVs. Deviation from the original Battery Directive**
	Option 3: 1 separate LMT + 2 portable subcategories	**Idem as Option 2: 3 subcategories for primary, portable rechargeable and LMT** correspond better with the environmental priorities and developing specific incentives in logistics, collection and recycling. **More forward looking** in case 'general purpose' batteries are replaced with rechargeable ones.	**LMT products still to be defined as for option 2. More complex and ambitious related to achieving higher collection amounts. Difference between primary and rechargeable needs to be monitored and reported at collection.**
	Option A: Product / device centric	**Simple** and coherent interpretation across member states	The Regulation aims at the battery (waste), not the product potentially subject to other legislation (battery removal provisions in e.g. the WEEE, ELV or Machinery Directives). The collection, handling and recycling properties are related to the battery, not the product. New products with new functionalities may appear.
	Option B: Battery / waste centric	Simple, more oriented towards the battery dimensions and handling properties. Weight is a more favorable option than capacity.	Batteries in the same L-category may be subject to different collection channels. Energy density is likely going up, for heavier products more range is desired. 'Capacity' needs to be defined.
	Option C: Combination of A & B	All batteries with similar properties are destined to their 'natural' collection channel designated categories (portable/EV).	**The definition will be more elaborate,** however a functional description would be required for any option.

1&2	Defining a lower limit		
	Option A: Product centric	Option B: Battery / waste centric	Option C: Combination of A & B
i)	Vehicle alike toys, tools and '**below**' → portable All non-type approved → LMT	**LMT > 0.5 kg (and/or 0.2 kWh)**	LMT batteries are **excluding** toys equipped with a battery as specified in the Toy Safety Directive 2009/48/EC and …
ii)	Idem + monowheels, e-scooters → portable But: only e-bikes → LMT	LMT > 2 kg (and/or 0.5 kWh)	
1&2	**Defining an upper limit**		
i)	All non-type approved + **L1eA** → LMT All above L1eA and higher → EV	LMT < 8 kg (and/or 2 kWh)	… all batteries in non-type approved wheeled vehicles and batteries in type approved L1e-L7e categories with a individual battery weight below **25** kg (and/ or **5** kWh). (excluding batteries in N,M,O…categories)
ii)	Idem, but all above **L3e-A2 and higher** → EV	**LMT < 25 kg (and/or 6 kWh)**	
iii)	No exclusion, all L1e-L7e → LMT	LMT < 100 kg (and/or 25 kWh)	

In case combination option 2C is considered, the weight based threshold between portable and industrial batteries, does not have to be aligned with decisions here. Two additional lines are proposed in order to clarify the low end distinction between toys and small LMT products that are intended for road use. Obviously, definition 9 and 12 are adjusted in a similar way as for Option 1C, but instead now including a threshold of 25 kg to distinguish LMT versus EV batteries (suggested changes in red):

Definition (8): 'portable battery' means any battery that:

– is sealed;

– weighs below 5 kg;

– is not designed for industrial purposes; and

– is neither an electric vehicle battery, nor a light electric vehicle battery nor an automotive battery;

- including toys equipped with a battery as specified in the Toy Safety Directive 2009/48/EC (TSD)

Definition (9): a 'light mean of transport' battery means any battery in wheeled vehicles that can be powered by the electric motor alone or by a combination of motor and human power, including vehicles of type-approved categories in the meaning of Regulation (EU) No 168/2013 and with a weight below 25 kg.

Consequently for consistency:

Definition (12): 'electric vehicle battery' means any battery specifically designed to provide traction to a vehicle of category L in the meaning of Regulation (EU) No 168/2013 and with a weight above 25 kg, or to a vehicle of categories M, N or O in the meaning of EU Directive 2007/46/EC.

2.6.3 Option 3: portable batteries as rechargeable and non-rechargeable subcategories

This option is similar to Option 2, with an added subcategorization of rechargeable versus non-rechargeable batteries. The potential advantage of this option relates to more focused monitoring and reporting in case a collection target is to be achieved on the subcategory level and will be further discussed in Chapter 4. Of course, a differentiation here would require more monitoring and reporting efforts. It is important to note from a categorisation perspective that the subcategories are already defined in the current legislative proposal. It is not suggested to differentiate other obligations nor to create a 'sixth' category here.

Definition (4): 'non-rechargeable battery' means a battery that is not designed to be electrically recharged;

Definition (5): 'rechargeable battery' means a battery that is designed to be electrically recharged;

2.6.4 Related articles to be reviewed

Although out of scope of this study, a change in categorisation potentially affects currently proposed requirements and internal consistency obviously cannot be ignored either.

Regarding consistency in thresholds: In particular the currently proposed 5 kg threshold used for differentiation of portable and industrial batteries needs to be compared to the proposed **split of 8 kg** in this study in case no separate LMT category is considered. This is less relevant in case both a lower and an upper limit of 25 kg (roughly 6 kWh) for the defining a separate LMT **in-between** category, which in this case does not have to be consistent with the 5 kg limit between portable and industrial batteries.

Regarding more specific requirements for LMT products, the advantage of an LMT in-between option is that for instance some of the information, state-of-health and durability requirements of respectively **Article 13 and 14** may be adapted to the specific characteristics of LMT products. Additionally, **Article 11** related to removability, is currently only referring to portable batteries and possibly **Article 51(4)** may need more precision to adapt to the LMT category characteristics as well. Of particular attention, **Article 59** related to reuse and remanufacturing is suggested to be further reviewed. Stakeholders reported safety concerns specifically related to safe repair and remanufacturing of e-bike batteries.

The consequences of the categorisation on the collection and recycling related articles is further discussed in Section 4.6.

3 Modelling future battery flows and quantitative evaluation of the options

Before evaluating various alternatives for the collection target, a market analysis is needed to understand the main trends for portable and LMT battery amounts to be expected for the EU market and their waste characteristics. Such information substantiates the need, or absence of the need, for an alternative approach for the collection target. Available information and data in the literature were integrated by information provided by stakeholders involved in various steps of the study (see Annex 2 and Annex 3 for the list of stakeholders involved). Data collected were used to estimate the size of flows of different types of batteries (according to Table 2) POM as well as available for collection.

In light of this study's research aims, the main source of data for primary batteries (both characteristics and volumes) between 2000 and 2021 is the RMIS datasets (Huisman et al., 2020). Concerning future trends of POM and technological development of primary batteries (capacity, energy density, lifetime), data were derived by personal communication with stakeholders involved in the project and validated during the workshops (see Annex 2 and Annex 3). In particular, the total amount of primary batteries in 2030 is comparable with data provided by Circular Energy Storage (CES, 2021). For rechargeable batteries data were aligned and comparable with the Impact Assessment of the Batteries Directive (Stahl et al., 2018;European Commission, 2020c; Öko Institute, 2021 and CES, 2021).

Data about characteristics of LMT batteries (current and future assumptions) as well as POM forecasts were estimated based on the information provided by LEVA, CONEBI and ACEM and then validated during the project workshops (see Annex 2 and Annex 3). The temporal boundaries of the study are 2000 – 2050. Considering the uncertainty of forecasting future trends of batteries, three scenarios are considered in the assessment:

1. Low Demand Scenario (LDS),
2. Medium Demand Scenario (MDS)
3. High Demand Scenario (HDS).

The LDS, MDS and HDS scenarios were already used by the authors in another context (European Commission, 2020a), using medium and long terms carbon neutrality. The definitions of the three scenarios are here adjusted to the context of the study, reflecting besides the baseline (MDS) the lowest (LDS) and highest (HDS) subsequent waste volumes.

The MDS represents the most plausible or baseline scenario. The LDS scenario assumes first of all a relatively low market input combined with important improvements of the battery technology, e.g. better performances of batteries, improved density of batteries, improved energy and resource efficiency and longer lifespans. These aspects translate into a lower demand for batteries compared to other scenarios. On the flip-side, the HDS assumes that battery technology will improve more slowly and more batteries will be POM with shorter lifespans and higher weights per piece, compared to the LDS and the MDS. Sources of data and assumptions behind the model are reported in this chapter according to the categories of products as illustrated in Table 1 in Section 1.3. Note that automotive and industrial batteries, included in the table for completeness, are not addressed in this report as out of the scope of this study. In the following sections, data are presented based on the classification provided by JRC (Huisman et al., 2020) which is updated for this study to explicitly include LMT batteries embedded in small PLEVs, scooters, bikes, mopeds and motorcycles (as in Table 2).

In the following sections, data used in the AfC study are illustrated for the following groups as presented in Table 2 in Section 2.1:

1. Portable primary batteries, including both alkaline batteries, lithium and other primary batteries;
2. Portable rechargeable batteries;
3. Batteries used in small PLEVs, including mono-wheels, hoverboards, e-skateboards, self-balancing vehicles etc., except e-scooters;
4. Batteries used in electric scooters, also referred to as e-kick-steps; (e-scooters);
5. Batteries used in electric bikes (e-bikes);
6. Batteries used in electric mopeds (e-mopeds), in some countries referred to as e-scooters;
7. Batteries used in electric motorcycles (e-motorcycles).

In this chapter, Section 3.1 summarizes the characteristics of the above-mentioned batteries categories (in relation to lifespan, capacity and weight), while market data for current and future flows of batteries in Europe are reported in Section 3.2. Section 3.3 reports the results of the developed assessment and sensitivity analysis for most important parameters are illustrated in Section 3.4.

3.1 Battery characteristics

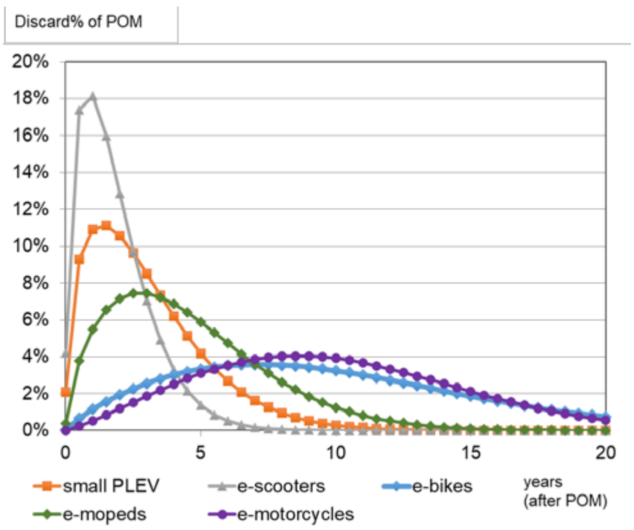
Increasing demand of LIBs to be used in different application is already a reality in Europe and, especially for some applications, this increase is expected to further grow very rapidly; this is the case of LMTs. Forecasting the volumes of such batteries is quite challenging as both market demand of products using different types of batteries (specific batteries, LIBs, high-energy performant batteries, etc.) is developing fast and new applications are entering in the European market. Moreover, batteries technologies are expected to evolve towards more efficient, lighter and sustainable batteries, increasing the performances and lifetime in various products. These aspects are all relevant to estimate the future flow of batteries POM as well as stock and flow of waste batteries in order to be properly collected and treated at their end-of-life.

Relevant aspects affecting the lifespan/residence time of batteries are the development of technology in terms of batteries' performances, strategies to extend their lifetime (e.g. repair, second-use), user behaviour (e.g. frequency of use, hoarding) and exports (Di Persio et al., 2020).

An overall increase of batteries' performances is already visible in the current market, and further improvements are expected in the next decade. In particular, the energy density of batteries is expected to increase for all chemistries available in the market, and new chemistries are already under development, even though not yet available at industrial scale. This is the case for instance of LFP (lithium iron phosphate) cell-to-pack batteries.

Increased energy density translates into an increased capacity and lower weight for batteries, i.e. potentially longer lifespan compared to current batteries and lower weight. This is particularly relevant for heavier batteries (e.g. LMT batteries) which are also expensive for consumers. The estimation of future trends of tonnages POM and AfC is even more complex due to these characteristics, batteries are in some cases stocked in houses, increasing the hoarding effect as consumers keeps them as backup batteries for different applications, or simply they consider the possibility to re-use them in the future. This is reflected in longer lifetimes and/or in more 'flattened' Weibull distributions as visualised in Figure 6.

Figure 6: Lifetime distribution LMT batteries MDS



3.1.1 Primary batteries

Primary (non-rechargeable batteries) includes both alkaline (incl. all zinc-carbon, manganese oxide of all sizes) batteries and lithium primary (all sizes) batteries. Characteristics of these types of batteries depend on the applications in which they are used.

The average capacity for alkaline batteries for all different sizes combined is around 5 Wh, with an average weight of 24 g; for Li primary batteries the average capacity is lower than 2 Wh, with an average weight of almost 6 g (Figure 7 and Figure 8). Focusing on lifetime of non-rechargeable batteries (Table 9), including the hoarding effect of stocking batteries before their collection, it is estimated an average lifetime of 4 years for the alkaline batteries and 6 years for Li primary batteries, which is aligned with Eucobat (2017).

Figure 7: Capacity for primary batteries for different scenarios and years [Wh/battery]

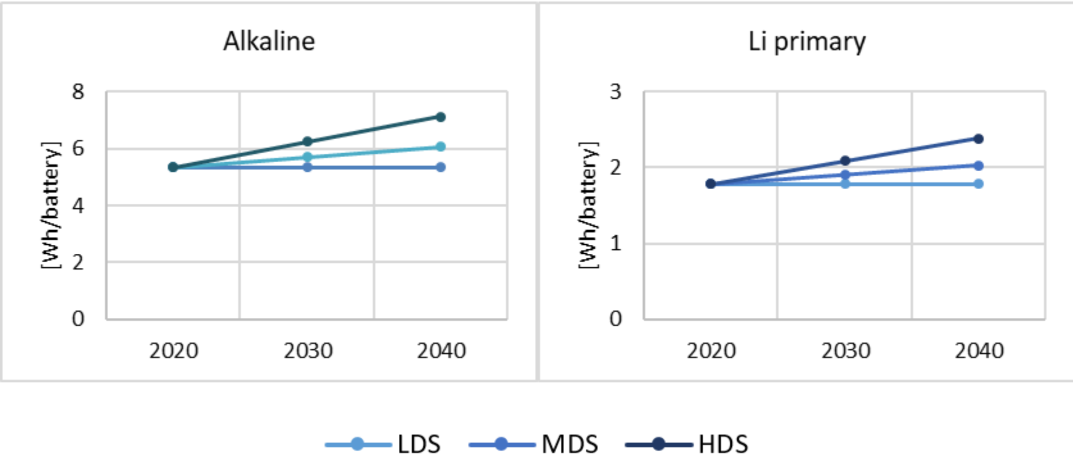


Figure 8: Weight for primary batteries for different scenarios and years [g/battery]

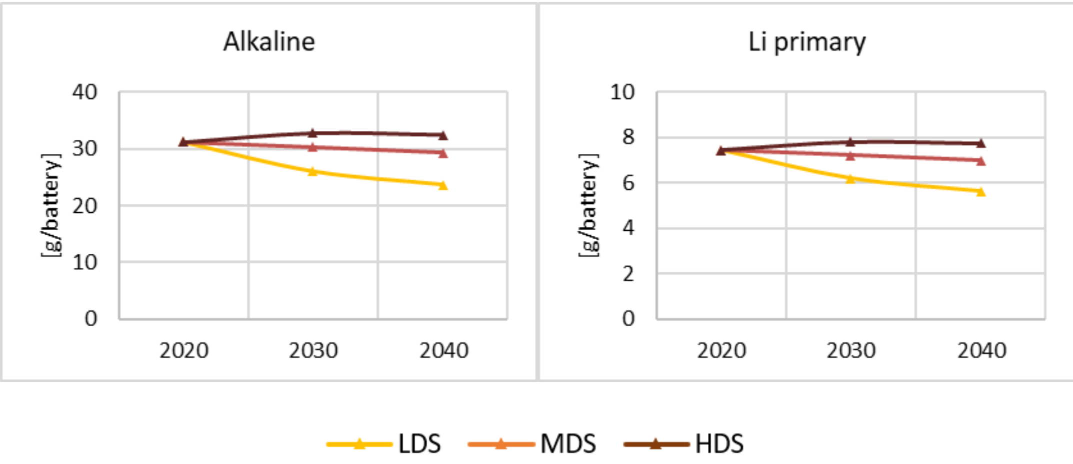


Table 9: Average lifetime values for primary batteries for different scenarios and years

Battery key	Unit of measure	Scenario	Value
Alkaline	[years]	LDS	4.9
		MDS	4.0
		HDS	3.7
Li primary	[years]	LDS	6.9
		MDS	6.0
		HDS	5.5

3.1.2 Rechargeable batteries

Rechargeable batteries include various type of chemistries, historically including NiCd and NiMH chemistries, but currently predominantly Li-ion and obviously no new NiCd and significantly declining NiMH market inputs. The typical applications of such batteries are portable PCs, cell phones, tablets and cordless tools and increasingly a wide range of newer applications where primary batteries of general use are replaced with an internal rechargeable one. According to the type of batteries considered, capacity can vary from 8 Wh to more than 90 Wh, and a typical weight from 15 g to 600 g. In the future, higher-performance batteries in terms of efficiency and capacity per unit of weight are expected, which means the potential decrease in weight of batteries whilst having an increased capacity per unit (Figure 9 and Figure 10). For the purpose of this study, we 'defined' for the LDS and HDS scenario as respectively the lowest versus highest weight per piece, based on the combined effects of (trends in) maximum desired weight per battery per application, energy density development and total capacity, aligned with the assumptions of the scenarios.

Figure 9: Capacity for rechargeable batteries for different scenarios and years [Wh/battery]

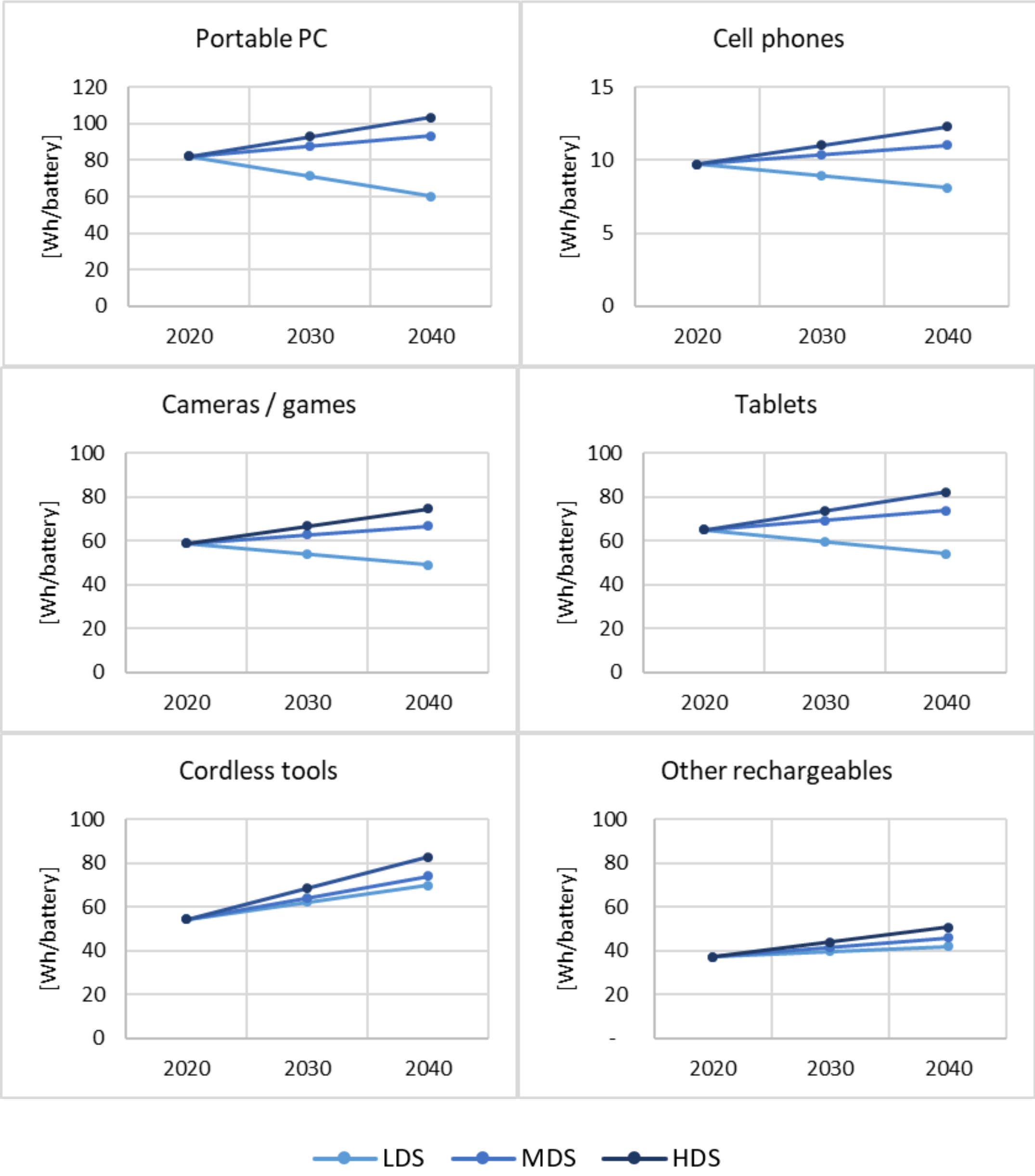


Figure 10: Weight for rechargeable batteries for different scenarios and years [g/battery]

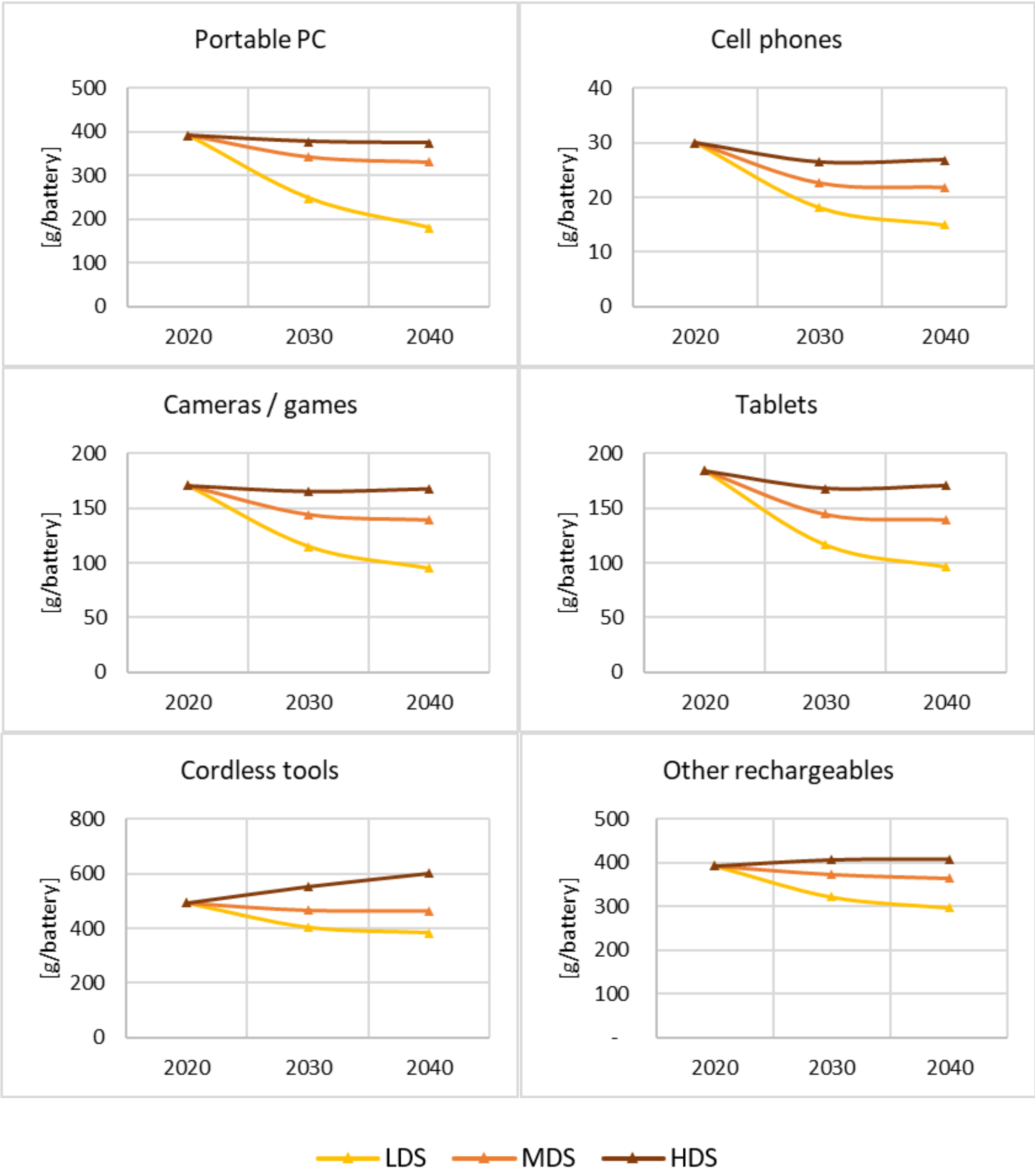


Table 10: Average lifetime values for rechargeable batteries for different scenarios and years

Battery key	Unit of measure	Scenario	Value
Portable PC	[years]	LDS	7.1
		MDS	6.2
		HDS	5.7
Cell phones	[years]	LDS	8.8
		MDS	7.5
		HDS	6.7
Tablets	[years]	LDS	8.8
		MDS	7.5
		HDS	6.7

Battery key	Unit of measure	Scenario	Value
Cameras / games	[years]	LDS	7.6
		MDS	6.7
		HDS	6.2
Cordless tools	[years]	LDS	11.8
		MDS	10.3
		HDS	9.3
Other rechargeable	[years]	LDS	9.1
		MDS	7.9
		HDS	7.2

3.1.3 LMT batteries

Small PLEVs batteries

Small PLEVs (personal light EVs) batteries are used in various type of vehicles like electric monowheels, electric self-balancing vehicles, electric hoverboards, and electric skateboards. Typical capacity of small PLEVs batteries ranges between 0.15 and 1.1 kWh, with the bulk having an average capacity of 0.4 kWh. This corresponds to batteries with an average weight ranging between 2 and 4 kg, even though lighter batteries are already available on the market. Data on lifespan of small PLEVs batteries are currently lacking due to the novelty of the market. However, many small LMT devices have a lifespan significantly shorter compared to e-bikes. According to available information in consumers' forum and technical data sheets of products, the average warranty for monowheels, self-balancing vehicles, e-scooters ranges between 1 and 2 years. However, there are examples of batteries for small LMT devices lasting up to 5 years. There is no evidence about exports of waste batteries from such devices, but the hoarding effects could be significant due to the relatively high battery value. Moreover, repair is a common practice and safety requirements are needed especially for handling LIBs. Both aspects contribute to increasing the residence lifespan of batteries used in small LMT devices. For the longer term, an improvement in average lifespan is factored in based on responses from stakeholders.

E-scooters batteries

Batteries used in e-scooters has a capacity ranging between 0.15 and 1.3 kWh, and a weight between 0.8 and 3 kg. Similar to small PLEVs batteries, there is not much information available on lifespan of batteries for e-scooters. From the research it emerged that the lifetime of e-scooters used in shared mobility is much lower compared to private e-scooters (can be as low as one month). However, shared e-scooters have become quite popular in many cities, representing an important share of the market of e-scooters. As a result, batteries are used relatively intensively leading to a relatively low lifespan compared to private ownership of the same product. When no more suitable to be used in e-scooters, batteries are likely to be repaired or hoarded. Aspects to be considered in estimating the residence time of batteries present in countries since they can heavily affect such a parameter. Nowadays, there are no insights about the flows of exported waste batteries or second-hand market of e-scooters (still with batteries embedded).

E-bikes batteries

Among the LMT, the majority of products is represented by EPAC25. The capacity of batteries used in e-bikes can vary between 0.6 kWh up to 0.8 kWh with an average capacity that increases from 0.5 kWh in 2015 up to 0.6 kWh in 2020. The typical average weight of such batteries is about 3 kg, considering lower and upper values between 2.6 and 6.5 kg.

For most countries, the market of e-bikes is still in its early development and few data of lifespan of batteries are available. The lifespan of batteries can range between 3 and 14 years, but the majority is expected to be used for around 10 years. It is reported that the far majority now are Li-ion batteries being mainly NMC and NCA chemistries and, depending of the use on the battery, they can technically last up to 20 years[12].

Due to the high cost of batteries, not all batteries are properly collected after their replacement as consumers prefer to keep the old battery (e.g. when it reaches 60% of the nominal capacity) as backup batteries or simply they keep batteries for some time in the house (i.e. hoarding) (Di Persio et al., 2020), which increases the residence time of batteries in the in-use stock.

E-mopeds batteries

As can be seen in Table 1 in Section 1.2, this category includes a wide range of products, and therefore various types of batteries. It is highlighted that in some cases, same batteries are used in different products for which the main difference is related to e.g. software characteristics; also, it could be the case that different products use the same type of batteries. This is reflected in the difficulty of having a robust representation of batteries used in e-mopeds and therefore the increased level of uncertainty in modelling the trends of batteries used in such products.
Batteries used in e-mopeds have a typical capacity ranging between 1.4 kWh and 4.8 kWh. This corresponds to a typical average weight of 12 kg, with lower and upper limit between 8 kg and 25 kg.

[12] Considering 50 full charges a year and a life cycle of 1,000 cycles

Especially due to the wide range of products fitting into the e-mopeds battery key, the lifetime of batteries used for these products ranges between 3 and 10 years (Moll et al., 2019). Note that in case of shared e-mopeds, the lifetime could importantly decrease, but the market for such products is still under development and uncertainty on this aspect requires further analyses.

E-motorcycles batteries

Similar to e-mopeds, e-motorcycles includes a wide range of products, using different batteries.

The capacity of e-motorcycles batteries can range between lower values of 7 kWh and upper values exceeding 25 kWh, and the average capacity is expected to increase further in the future due to the increasing demand of more performant batteries. As a consequence, the weight of e-motorcycles batteries can be very high (e.g. 275 kg); however, this is expected to decrease for the bulk of e-motorcycle due to more performant batteries and the fact that motorcycle designers strive to keep the weight of e-motorcycles as low as possible.

Due to the novelty and the low volumes of e-motorcycles currently on the European roads, almost no data about lifespan of e-motorcycles are available. According to Moll et al. (2019), batteries of e-motorcycles can last on average 10 years.

Figure 11: Capacity for LMT batteries for different scenarios and years [kWh/battery]

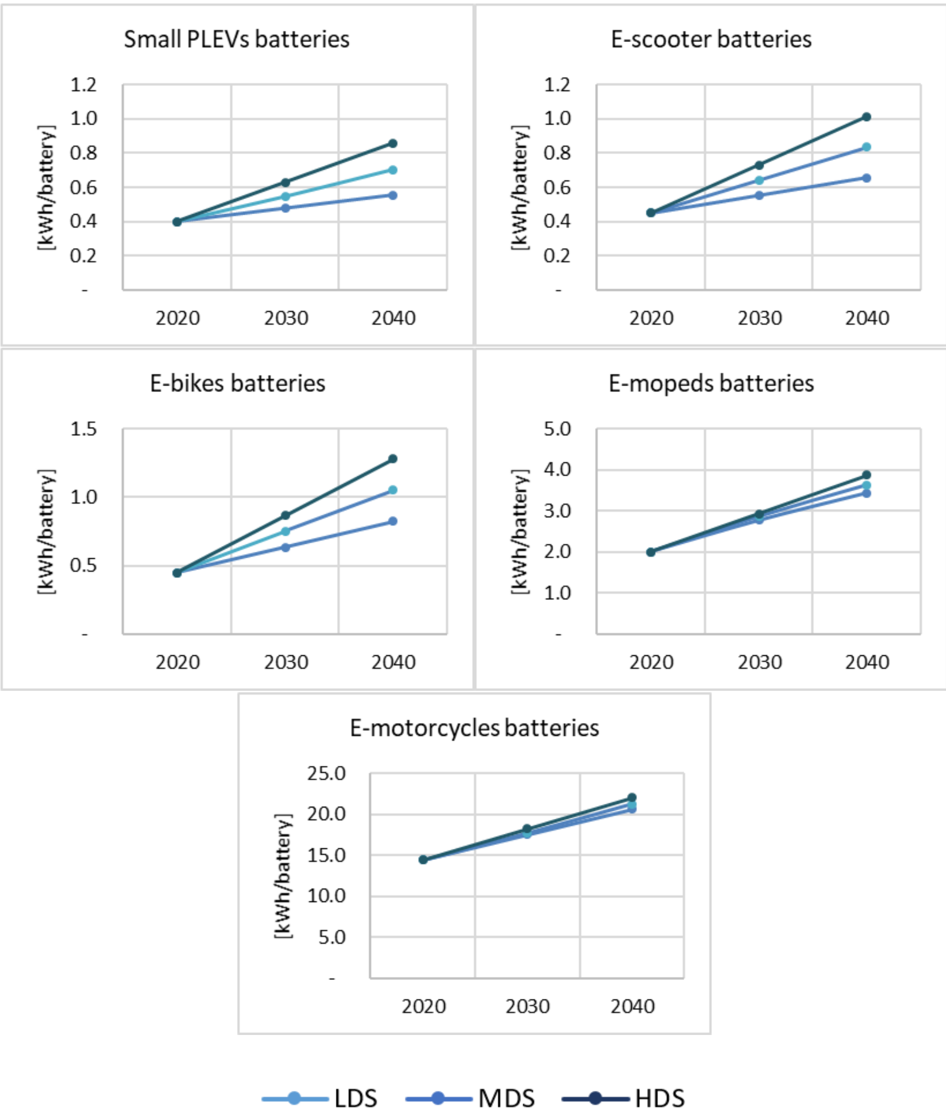


Figure 12: Weight for LMT batteries for different scenarios and years [kg/battery]

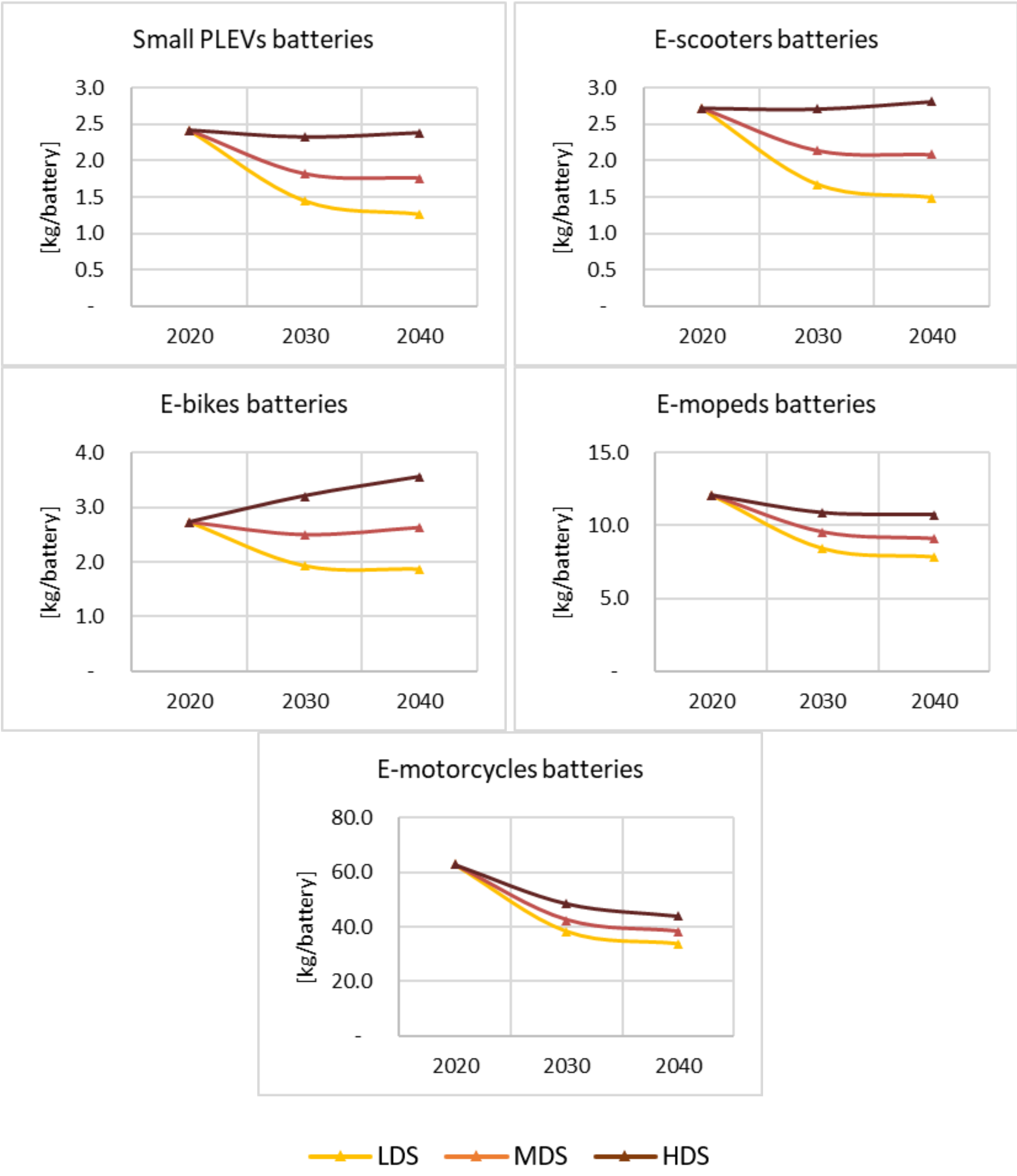


Table 11: Lifetime values for LMT batteries for different scenarios and years

<table>
<tr><th>Battery key</th><th>Unit of measure</th><th>Scenario</th><th>2020</th><th>2030</th><th>2040</th></tr>
<tr><td rowspan="3">Small PLEVs</td><td rowspan="3">[years]</td><td>LDS</td><td colspan="3">4.0</td></tr>
<tr><td>MDS</td><td>3.0</td><td>2.7</td><td>3.4</td></tr>
<tr><td>HDS</td><td colspan="3">3.6</td></tr>
<tr><td rowspan="3">E-scooters</td><td rowspan="3">[years]</td><td>LDS</td><td colspan="3">0.9</td></tr>
<tr><td>MDS</td><td>1.8</td><td>1.3</td><td>2.2</td></tr>
<tr><td>HDS</td><td colspan="3">1.5</td></tr>
<tr><td rowspan="3">E-bikes</td><td rowspan="3">[years]</td><td>LDS</td><td colspan="3">11.3</td></tr>
<tr><td>MDS</td><td colspan="3">10.0</td></tr>
<tr><td>HDS</td><td colspan="3">8.6</td></tr>
</table>

E-mopeds	[years]	LDS	7.0
		MDS	4.6
		HDS	2.8
E-motorcycles	[years]	LDS	10.9
		MDS	10.0
		HDS	9.1

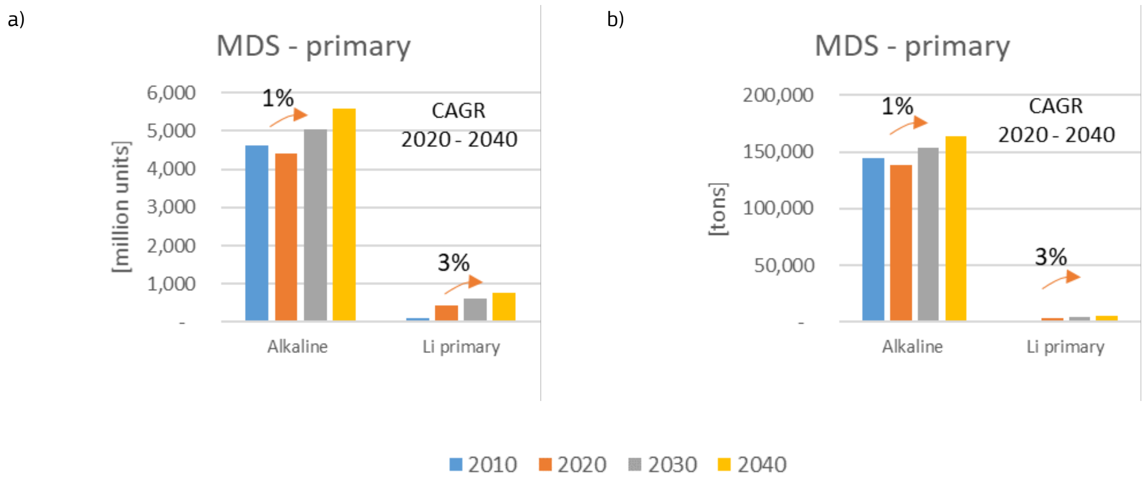
3.2 Batteries flows: batteries put on the market and waste batteries

For this study, rechargeable + LMT results are comparable with the estimates available in the Impact Assessment provided by Öko-Institute (European Commission, 2020c) and Circular Energy Storage (CES, 2021).

3.2.1 Portable primary batteries

Portable primary (non-rechargeable) batteries POM in the EU until 2021 are based on JRC[13] data and feedbacks provided by stakeholders consulted along the research.
The portable primary batteries POM in the EU between 2010 and 2040 increase from 4,900 million units in 2010 up to 6,200 million units in 2050 (+26%) (Figure 13). The assumed Compound Annual Growth Rate (CAGR [14]) for the different type of portable primary batteries are displayed in Annex 5. More information about the weight and the capacity per battery units, as well as the lifetime per battery key is available in Annex 4.
Weibull distributions are used to model the lifespan of alkaline and Li primary batteries, and to estimate the volumes of stocks and waste batteries in Europe (**Figure 14**).

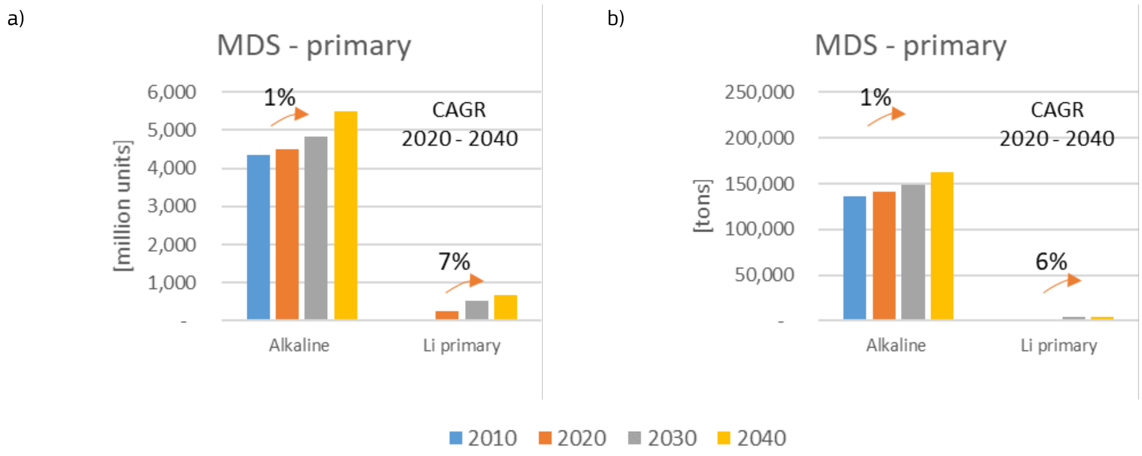
Figure 13: Units (a) and tonnage (b) of portable primary batteries POM in different years for the Medium Demand Scenario (MDS) and the CAGR (Compound Annual Growth Rate) between 2020 and 2040



The CAGR (compound annual growth rate) between 2020 and 2040 reported in the figure is calculated as the average between the CAGR 2020-2030 and the CAGR 2030-2040.

[13] https://rmis.jrc.ec.europa.eu/apps/bvc/#/
[14] CAGR (200X-200Y) = [(Value$_{200Y}$ / Value$_{200X}$)-1] / (200Y – 200X)

Figure 14: Units (a) and tonnage (b) of waste portable primary batteries in different years for the Medium Demand Scenario (MDS) and the CAGR (Compound Annual Growth Rate) between 2020 and 2040



The CAGR (compound annual growth rate) between 2020 and 2040 reported in the figure is calculated as the average between the CAGR 2020-2030 and the CAGR 2030-2040.

3.2.2 Portable rechargeable batteries

Portable rechargeable batteries POM in the EU until 2021 are based on JRC[15] data and feedbacks provided by stakeholders consulted along the research.

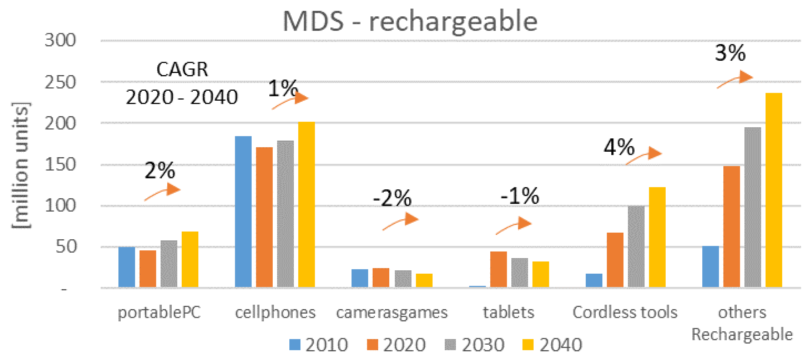
The portable rechargeable batteries POM in the EU between 2010 and 2040 increase from 330 million units in 2010 up to 680 million units in 2050 (+105%). The assumed CAGR of portable primary batteries are reported in Annex 5. The tonnage of portable primary batteries POM was estimated according to different battery keys (Table 1). More information about the weight and the capacity per battery units, as well as the lifetime per battery key is available in the Annex 4.

Weibull distributions are used to model the lifespan of alkaline and Li primary batteries, and to estimate the volumes of stocks and waste batteries in Europe (**Figure 15**).

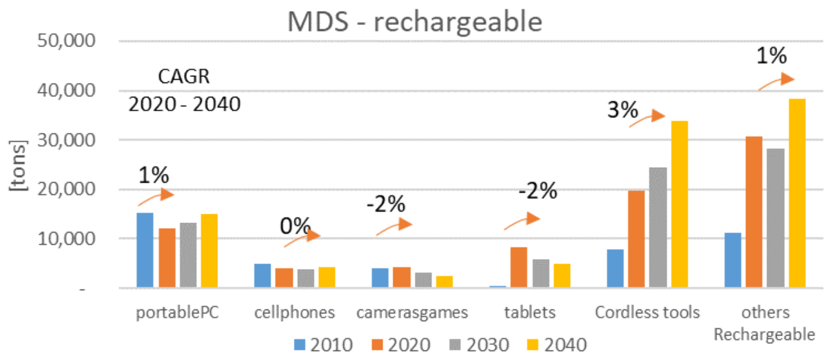
[15] https://rmis.jrc.ec.europa.eu/apps/bvc/#/

Figure 15: Units (a) and tonnage (b) of rechargeable batteries POM in different years for the Medium Demand Scenario (MDS) and the CAGR (Compound Annual Growth Rate) between 2020 and 2040

a)



b)

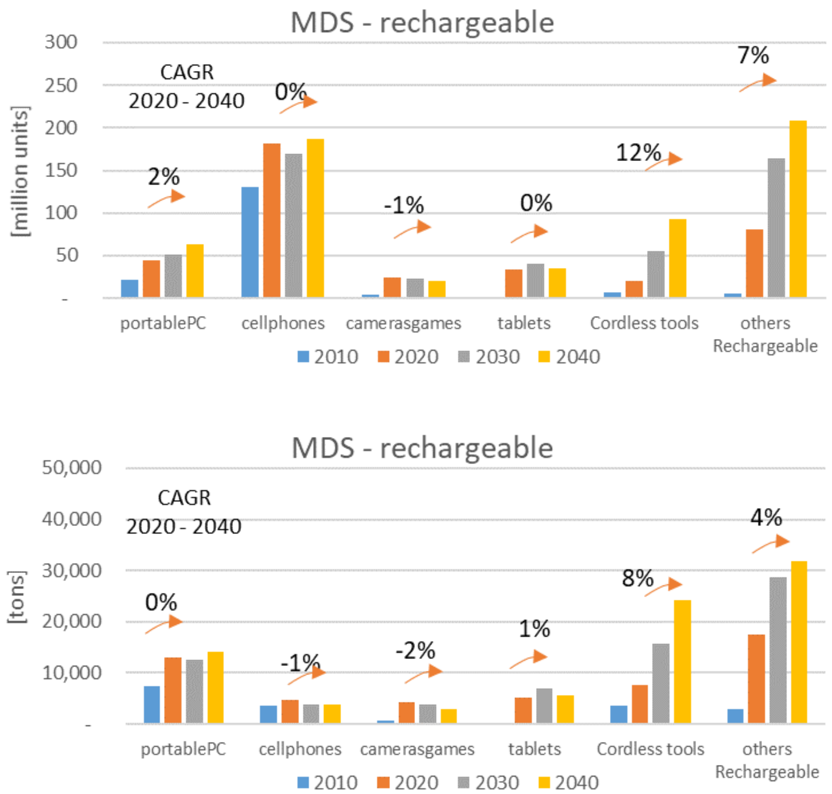


The CAGR (compound annual growth rate) between 2020 and 2040 reported in the figure is calculated as the average between the CAGR 2020-2030 and the CAGR 2030-2040.

Figure 16: Units (a) and tonnage (b) of waste rechargeable batteries in different years for the Medium Demand Scenario (MDS) and the CAGR (Compound Annual Growth Rate) between 2020 and 2040

a)

b)



The CAGR (compound annual growth rate) between 2020 and 2040 reported in the figure is calculated as the average between the CAGR 2020-2030 and the CAGR 2030-2040.

3.2.3 Batteries used in Light Means of Transport (LMT)

Aligned to the battery keys defined for this study and reported in Table 2, LMT batteries POM in Europe are based on feedbacks provided by stakeholders consulted along the research.

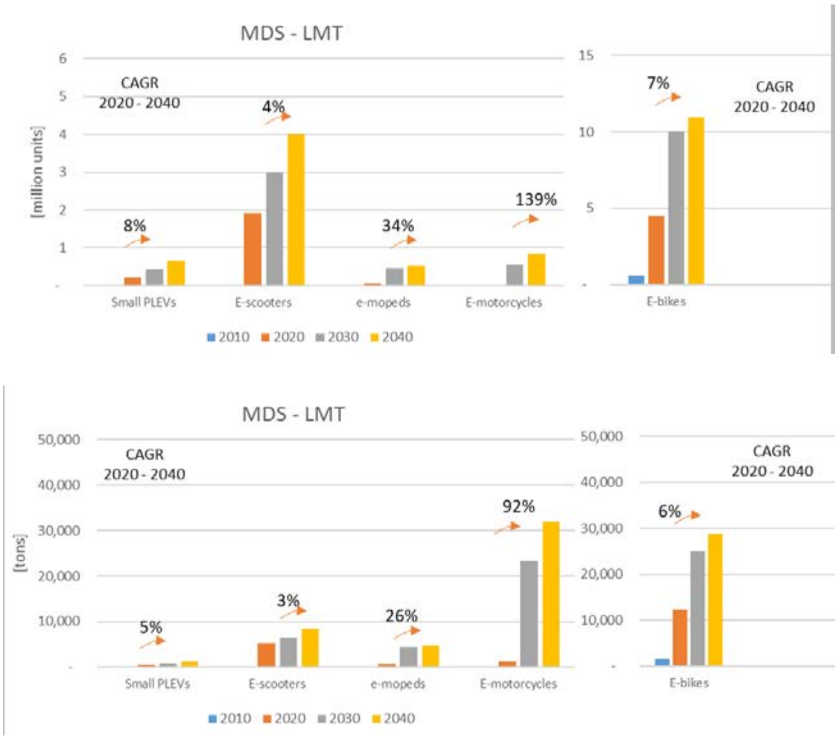
The LMT batteries POM in the EU between 2010 and 2040 increase from less than 1 million units in 2010 up to 17 million units in 2040. The assumed CAGR of portable primary batteries are reported in Annex 5. It is highlighted that the bulk of the LMT batteries is represented by batteries used in e-bikes, including EPAC25, which are not type-approved according to the Regulation 168/2013). Note that in below figure the CAGR values for e-mopeds and e-motorcycles as relatively new products are very high since there are currently only few products placed on market.

The tonnage of LMT batteries POM was estimated according to different battery keys (Figure 17). More information about the weight and the capacity per battery units, as well as the lifetime per battery key is available in the Annex 5. Weibull distributions are used to model the lifespan of alkaline and Li primary batteries, and to estimate the volumes of stocks and waste batteries in Europe (Figure 18).

Figure 17: Units (a) and tonnage (b) of LMT batteries POM in different years for the Medium Demand Scenario (MDS) and the CAGR (Compound Annual Growth Rate) between 2020 and 2040

a)

b)

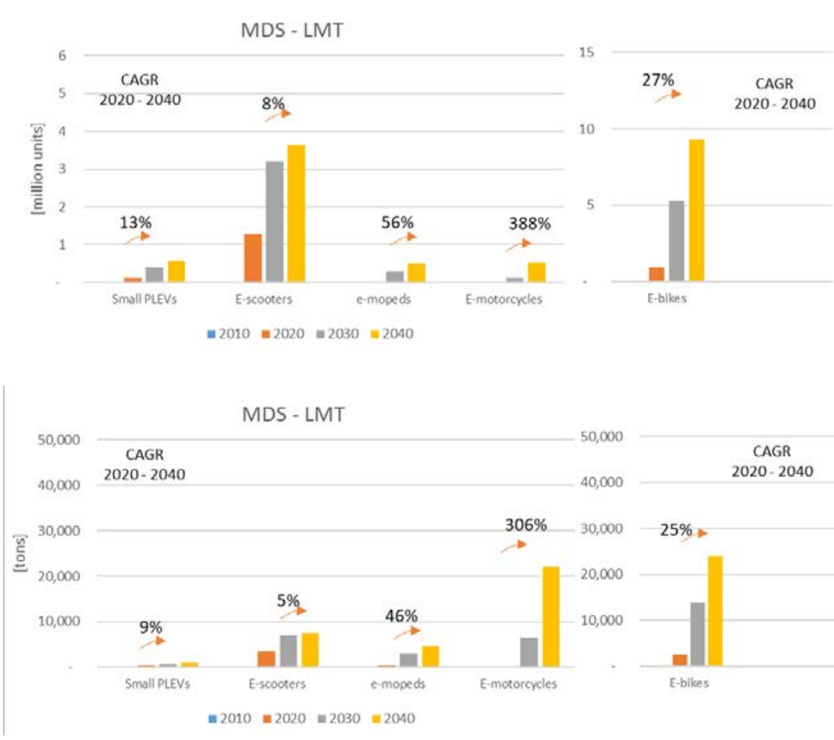


The CAGR (compound annual growth rate) between 2020 and 2040 reported in the figure is calculated as the average between the CAGR 2020-2030 and the CAGR 2030-2040.

Figure 18: Units (a) and tonnage (b) of waste LMT batteries in different years for the Medium Demand Scenario (MDS) and the CAGR (Compound Annual Growth Rate) between 2020 and 2040

a)

b)



The CAGR (compound annual growth rate) between 2020 and 2040 reported in the figure is calculated as the average between the CAGR 2020-2030 and the CAGR 2030-2040.

3.3 Results of the first evaluation of options 1, 2 and 3 using market data

In this section, the main results of the estimation of stock and flows based on data presented in Section 3.1 and 3.2 are presented. The following figures reports the tonnage of POM batteries (**Figure 19**), of stock (**Figure 20**) and waste batteries (**Figure 21**) in Europe between 2015 and 2035 for different scenarios.

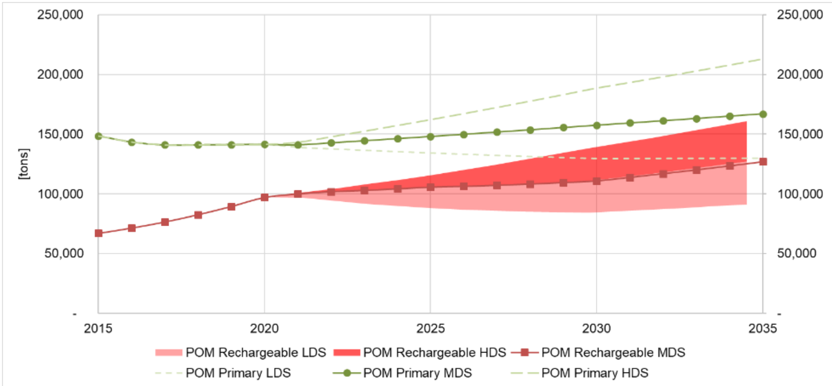
3.3.1 Placed on market

Results are presented according to Option 1, assuming an 8 kg limit would exclude all e-mopeds and Option 2/3 as illustrated in Section 2.2, assuming a 25 kg limit matches with the scenario of excluding motorcycles, whereas including the entire L-category matches with the inclusion of larger e-motorcycles.
Results show that flows of primary batteries (green lines) are quite stable along time, while flows of portable rechargeable batteries (red and orange lines) is increasing. The increase is faster in case LMT batteries belong to portable rechargeable category (Option 1 in **Figure 19**), even though it is to be noticed that e-mopeds and e-motorcycles are not included in such a flow.

Figure 19: Flow of batteries POM between 2015 and 2030 in Europe, according to the Options illustrated in Section 2.2

Option 1:
1 portable category
including (part of) LMT

Rechargeable batteries, **including** small PLEVs, e-scooters and e-bikes batteries



Rechargeable include all rechargeable portables + ‘small PLEVs’, ‘e-scooters’ and ‘e-bikes’ batteries

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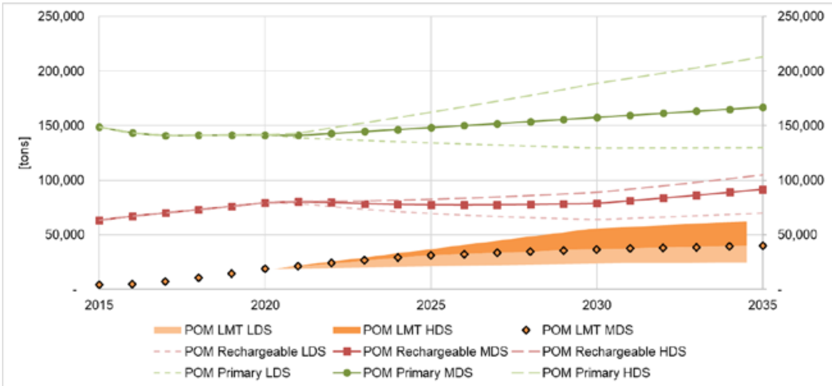
Option 2:
1 separate LMT
+ 1 portable category

Option 3:
1 separate LMT
+ 2 portable subcategories

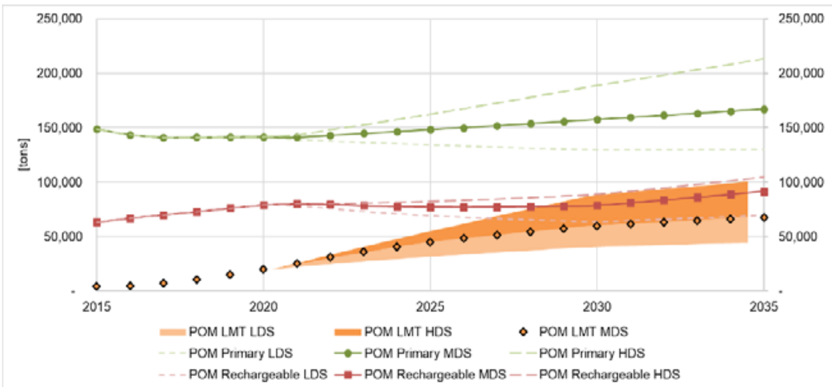
Excluding e-motorcycles



Option 2:
1 separate LMT
+ 1 portable category

Option 3:
1 separate LMT
+ 2 portable subcategories

Including e-motorcycles



Note that MDS is represented by lines while LDS and HDS are visualised by areas

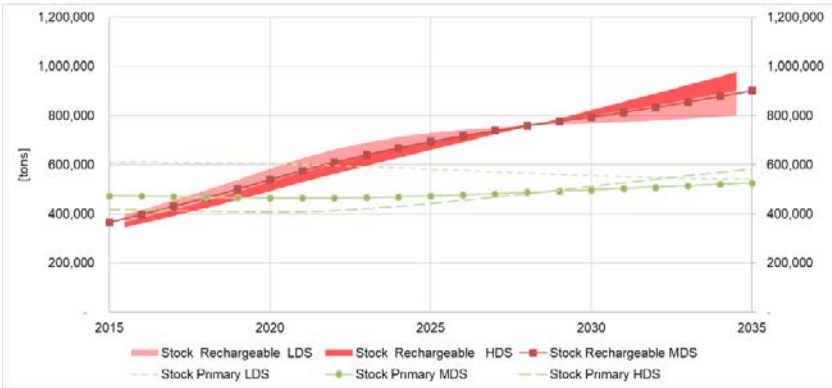
3.3.2 Stocks

As observed from **Figure 20**, the stock of rechargeable batteries will surpass the stock of primary batteries around 2020. This is mainly related to the higher lifetime of rechargeable batteries compared to the primary ones and the fast increase of the market compared to a more stable market of primary batteries.

Figure 20: Stock of batteries between 2015 and 2030 in Europe, according to the Options illustrated in Section 2.2

Option 1:
1 portable category
including (part of) LMT

Rechargeable batteries, **including** small PLEVs, e-scooters and e-bikes batteries

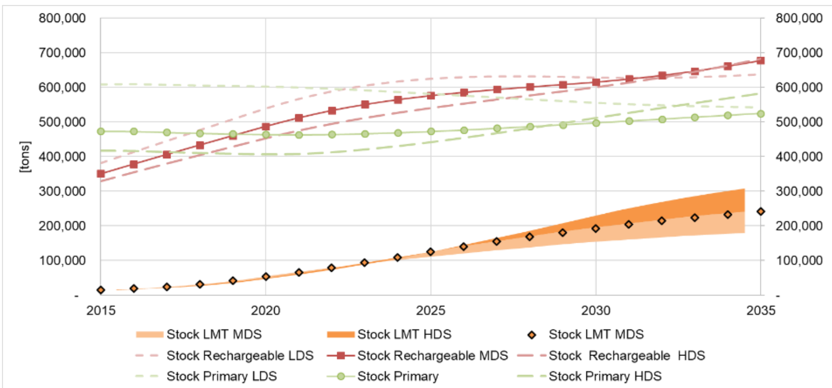


Rechargeable include all rechargeable portables + ‘small PLEVs’, ‘e-scooters’ and ‘e-bikes’ batteries

Option 2:
1 separate LMT
+ 1 portable category

Option 3:
1 separate LMT
+ 2 portable subcategories

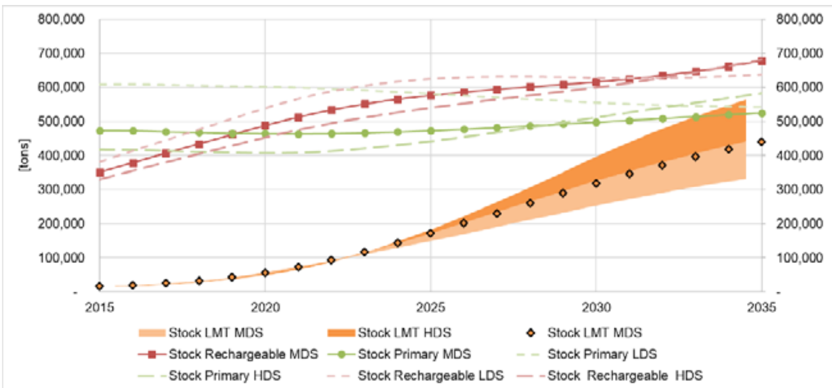
Excluding e-motorcycles



Option 2:
1 separate LMT
+ 1 portable category

Option 3:
1 separate LMT
+ 2 portable subcategories

Including e-motorcycles



Note that MDS is represented by lines while LDS and HDS are visualised by areas

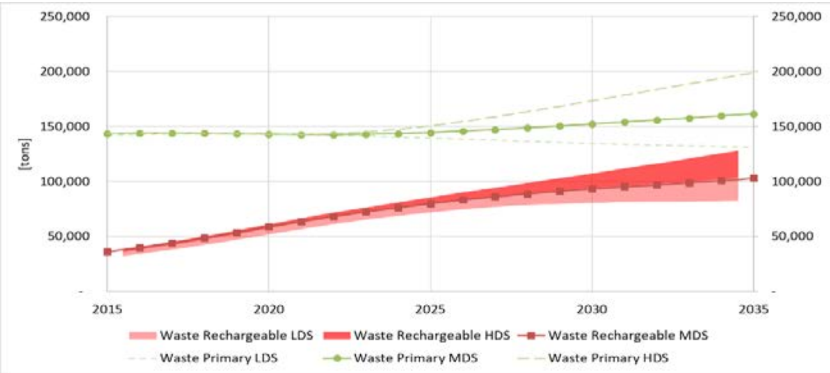
3.3.3 Waste generated

Figure 21 shows that trend of waste batteries flows follows the trend of batteries POM, even though curves are shifted in time according to the lifetime of specific batteries. Focusing on LMT category (Option 2 and Option 3), a fast increase of POM is observed from 2025, while a similar tonnage for waste batteries will be available only from 2025, which is due to the long lifetime of batteries used in LMTs.

Figure 21: Flow of waste batteries between 2015 and 2030 in Europe, according to the Options illustrated in Section 2.2

Option 1:
1 portable category
including (part of) LMT

Rechargeable batteries, **including** small PLEVs, e-scooters and e-bikes batteries



Rechargeable include all rechargeable portables + ‘small PLEVs’, ‘e-scooters’ and ‘e-bikes’ batteries

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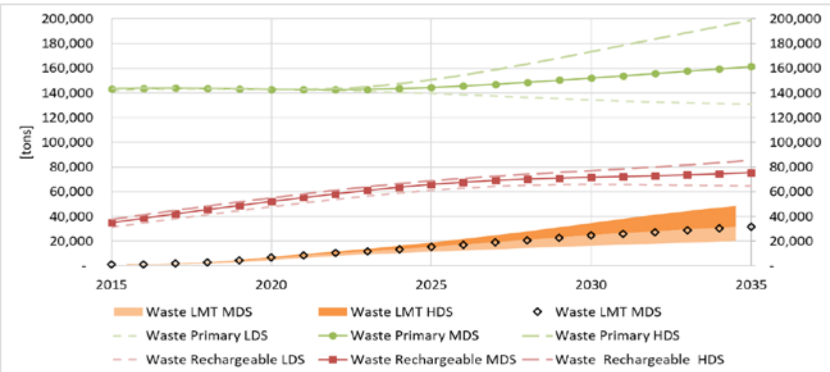
Option 2:
1 separate LMT
+ 1 portable category

Option 3:
1 separate LMT
+ 2 portable subcategories

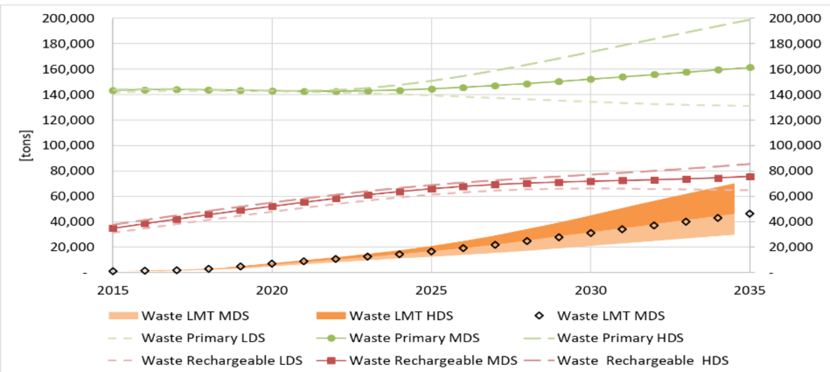
Excluding e-motorcycles



Option 2:
1 separate LMT
+ 1 portable category

Option 3:
1 separate LMT
+ 2 portable subcategories

Including e-motorcycles



Note that MDS is represented by lines while LDS and HDS are visualised by areas

Note that, in case of exclusion of e-motorcycles, the flow of waste LMT batteries (similar to POM flows) will be significantly lower in the future, as e-motorcycles batteries has higher weight compared to other LMT batteries.

3.3.4 Correspondence levels between POM and Waste Generated

Based on the obtained results, the tonnage of batteries to be collected according to the POM-based target are calculated based on the levels included in the proposal for the Batteries Regulation (i.e. 45 % by 31 December 2023, 65 % by 31 December 2025, and 70 % by 31 December 2030). To ease the comparison between different options, the correspondence targets between current targets in the Batteries Regulation and the AfC target for the different batteries categories are estimated. For the research purpose of this study: it is assumed the $POM_{3\ years}$ target to apply to LMT batteries as well as portable rechargeable and primary equally to enable a fair comparison. Note that the options compared here are different to the choice made in the proposal, with a postponement of the collection rate for LMT batteries. The latter does not mean there is no collection of LMT batteries taking place in practice.

Since the $POM_{3\ years}$ target does not reflect the lifespan differences between ranges of products evaluated, nor market input fluctuations in numbers of products POM, the key question is: **how do the currently proposed levels correspond with an approach that would be calculating the actual waste potential?** In order to determine this, the '*POM volumes*' are multiplied by the '*$POM_{3\ years}$ target*' to obtain the volume of waste batteries to be collected according to the 2020 proposal ('*POM3 years volume to be collected*' in the following figures). This value is then compared to the actual '*PAfC volume*' and expressed as the percentage of that volume that needs to be collected to match the $POM_{3\ years}$ target for each year ('*Corresponding PAfC target*'). Hence, the **corresponding PAfC target** is calculated as:

$$\text{Corresponding PAfC target [\%]} = \frac{(\text{POM volumes}) \cdot (POM_{3\ years}\ \text{target})}{(\text{PAfC volume})} =$$
$$= \frac{(POM3\ years\ volume\ to\ be\ collected)}{(\text{PAfC volume})}$$

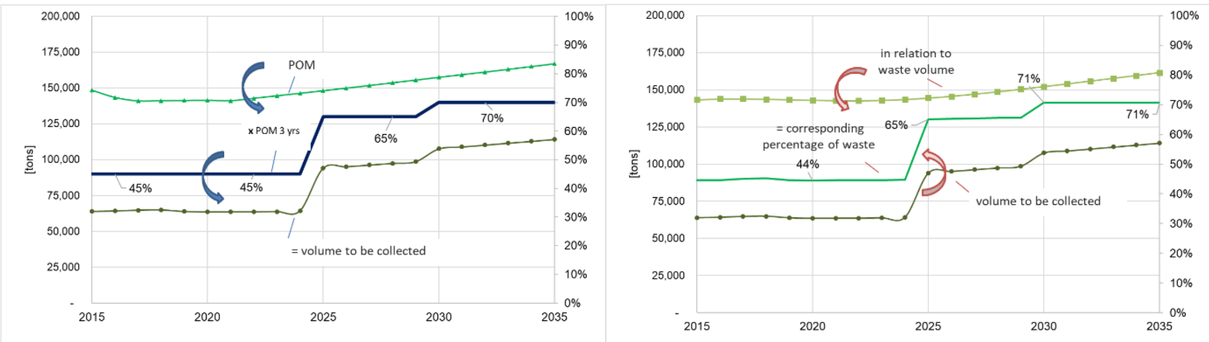
With:

- POM volume: volume of batteries POM in a specific year, [tons];
- $POM_{3\ years}$: collection target as in the current Batteries Directive (POM based), [%];
- PAfC volume: volume of waste generated batteries, [tons].

The '*Corresponding PAfC target*' was calculated for primary batteries, rechargeable batteries and LMT batteries according to the Options as presented in Section 2.2 and results are visualized in Figures 22 – 27; the left side of the figure report the '*POM volumes*' (lighter lines) and the '*$POM_{3\ years}$ volume to be collected*' (darker lines) calculated based on the '*$POM_{3\ years}$ target*' (plain lines), while on the right side of the figure, the '*Corresponding PAfC target*' (plain lines) is calculated based on the '*$POM_{3\ years}$ volume to be collected*' (darker lines) and the '*PAfC volume*' as reported in Section 3.3.3 (lighter lines).

Considering Option 1, it is observed that for primary batteries (**Figure 22**), the '*$POM_{3\ years}$ target*' and the '*Corresponding PAfC target*' are practically the same. For instance, in 2030, the '*$POM_{3\ years}$ target*' (70%) corresponds to 71% of '*PAfC volume*' for primary batteries. The reason is that the market for primary batteries obviously is relatively steady over time, with short-lived products.

Figure 22: Primary batteries (same volume for all 3 options)



For rechargeable batteries and LMT batteries both separately (Option 2 and 3) or together (Option 1), however, the '*Corresponding PAfC targets*' are deviating. In case of Option 1 (LMT batteries belong to rechargeable batteries, excluding e-mopeds and e-motorcycles batteries) (Figure 23), the '*Corresponding PAfC target*' deviates significantly from the step-wise increasing '*$POM_{3\ years}$ target*', especially in the years a new level is to be achieved. This discrepancy between '*POM volume*' and '*PAfC volume*' is caused by market dynamics and the fact that new products have significantly higher lifespans. A similar effect is observed also for Option 2 and 3 (**Figure 24**) where LMT batteries are singled out from the portable rechargeable subcategory. Here, for rechargeable batteries in 2030 the '*$POM_{3\ years}$ target*' (70%) corresponds to a '*PAfC target*' of 81% in case of Option 1, and of 76% of in case of Option 2 and 3.

A more extreme mismatch is observed for LMT batteries (**Figure 25**and **Figure 26**), for which, in 2030, the '*$POM_{3\ years}$ target*' (70%) corresponds to a '*PAfC target*' of 113% in case of Option 2 and 3 when excluding e-motorcycles from the LMT category, and 140% in case of Option 2 and 3 when including e-motorcycles into the LMT category. This means that to reach the '*$POM_{3\ years}$ target*' (70%), a volume higher than the '*PAfC volume*' should be collected, which is simply not achievable.

The comparison of '*POM volume*' and '*PAfC volume*' revealed an 'unknown and 'unintended' consequence of the originally proposed target basis. The more dynamic the market will be with significant volumes of new battery types, plus the longer the lifespan of newer batteries, the less representative the POM_{3y} approach will be. In such case, the target may become disproportionally high in 2025 and 2030 and disproportionally low in later years as displayed in the next Figures 23-26.

Figure 23: Rechargeable including LMT batteries in case of Option 1

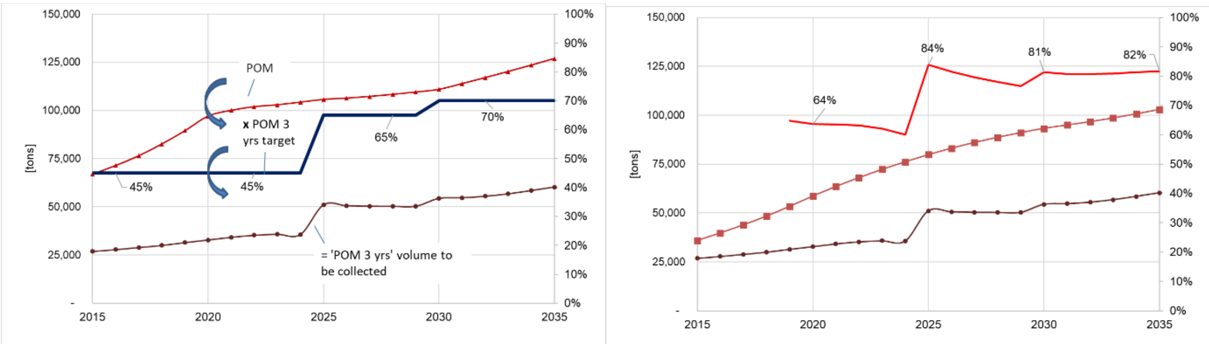


Figure 24: Rechargeable batteries in case of Option 2/3

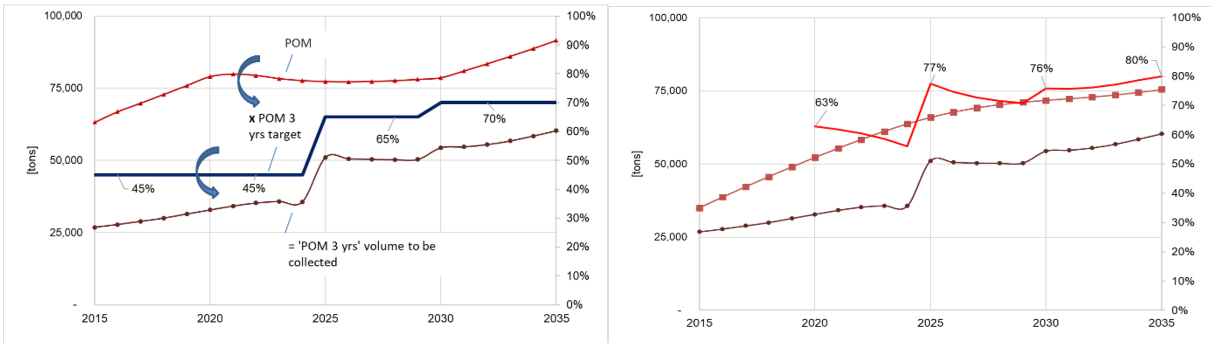


Figure 25: LMT batteries in case of Option 2/3 (excluding e-motorcycles batteries)

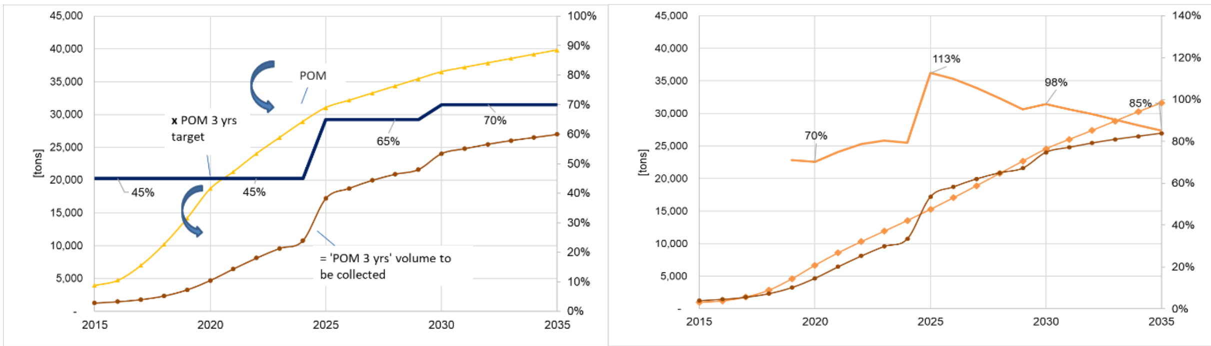
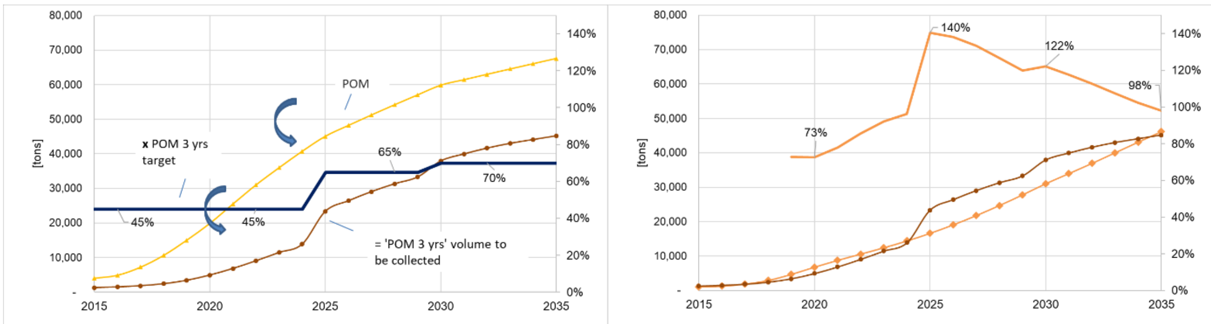
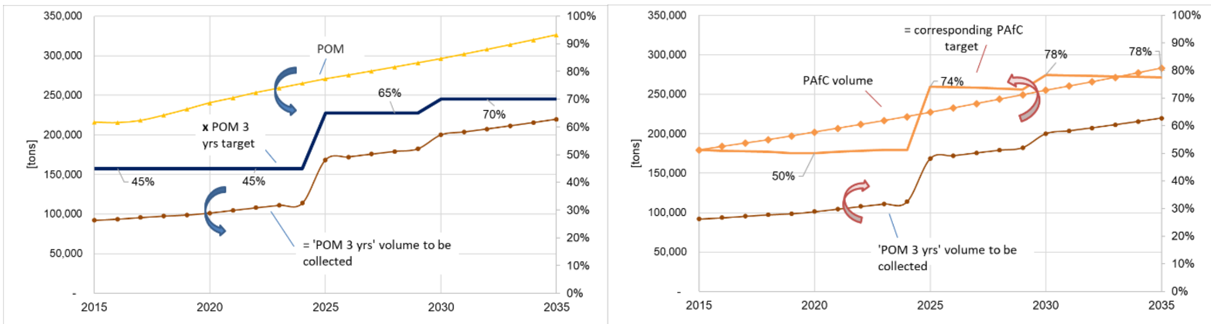


Figure 26: LMT batteries in case of Option 2/3 (including e-motorcycles batteries)



Focusing on all portable and LMT batteries aggregated (**Figure 27**), it is observed that differences emerged in the analysis of individual batteries categories are less pronounced due to the bulk of primary batteries. Since waste LMT batteries will be AfC later as compared to primary batteries, this may form an incentive to reach the targets by collecting relatively more primary batteries.

Figure 27: Portable and LMT batteries in case of Option 1 (including e-motorcycles batteries)



Based on the above illustrated results, it is observed that the current adopted 'POM3 years target' as currently adopted is not capturing the dynamic market of rechargeable batteries (used in various products, including LMT products). Increased durability of batteries turns in a 'PAfC volume' of batteries lower than the 'POM3 years volume to be collected'. This causes a non-linear (and in some case even decreasing) trend of the 'Corresponding PAfC target'. In order to maintain the same collection ambition of the current regulatory proposal, in Section 4.4 the approach as illustrated in this section is used to determine at which 'Corresponding PAfC target' the same 'PAfC volume' should be achieved between 2023 and 2035.

In conclusion, based on the above illustrated results, in case a separate LMT category would be introduced, it is inevitable to tailor the targets according to the market characteristics of individual battery types, taking into account different lifespans and use practices. If not, the current targets are clearly impossible to achieve for LMT batteries in the coming years.

It is to be highlighted that the results illustrated in this section are not taking into account the flows of (reported) import/exports of waste batteries, which emerged as very important aspects to be considered in such an analysis. This is mainly due to a lack of available data about these flows. Having more representative figures of various geographical areas in the EU will allow the inclusion of this aspect in the future.

3.4 Sensitivity analysis

Besides the three LDS, MDS and HDS scenarios presented above, the high level of uncertainty, especially when addressing new products in the European market, is further evaluated by conducting a sensitivity analysis. The MDS scenarios is considered as the baseline for the sensitivity analysis in order to check the relevance of the following aspects:

- Influence of lifespan of products
- Influence of technological improvements, mainly related to the fast/slow increase of the energy density and capacity of batteries packs of different type of batteries (and consequently fast/slow decrease of weight)

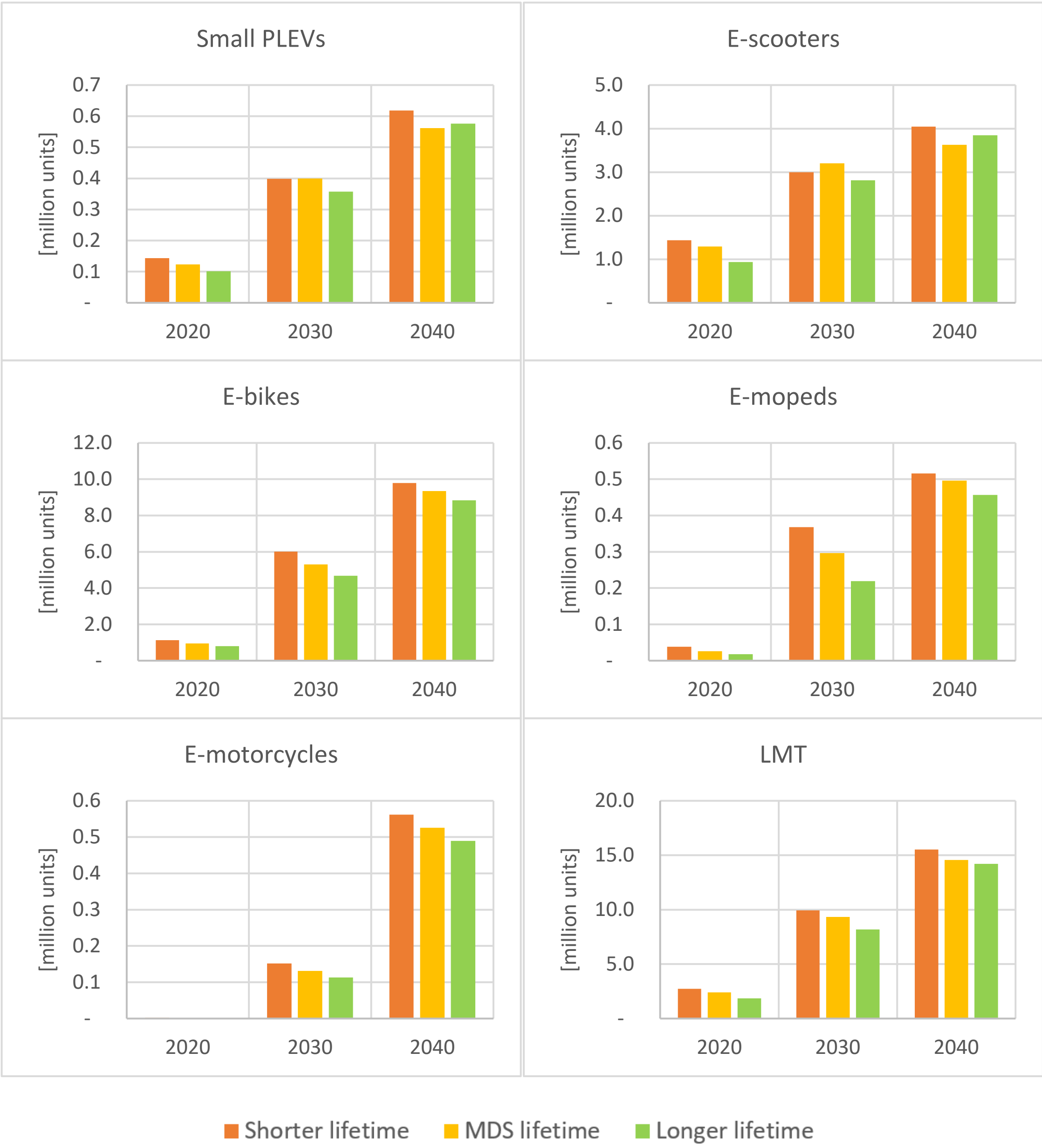
The effect of different market inputs in number of units is already visualised in Section 3.3. It has to be noted that these LDS and HDS scenarios are relatively conservative, whereas the market may be more dynamic than this study can anticipate.

Variation of the lifespan

As shown in **Figure 28**, higher or lower lifespan for LMT batteries do not significantly affect the size of waste batteries volumes in the next future. Main differences are related to e-mopeds, in the short term. From a long term perspective (2030-2040), lower lifetime relates to higher flow of waste batteries compared to the MDS scenario, but the difference is never exceeding 6 percentage points in 2030 and 2040 when looking at all LMT battery volumes together.

This will affect the corresponding PAfC target: in case of lower lifespan, the corresponding PAfC target of LMT batteries will decrease compared to the one presented in Section 3.3.4 (focusing on 2025, 103% in case of excluding e-motorcycles and 127% in case of including e-motorcycles, compared to respectively 113% and 140% of the MDS scenario). On the other side, in case of higher lifespans, the corresponding PAfC target of LMT batteries will increase compared to the one presented in Section 3.3.4 (focusing on 2025, 132% in case of excluding e-motorcycles and 164% in case of including e-motorcycles, compared to respectively 113% and 140% of the MDS scenario).

Figure 28: Number of waste batteries for 2020, 2030 and 2040 in Europe varying the lifespan of batteries



Variation of the energy density (lower weight per battery)

The uncertainty related to the potential technological improvements is addressed through the variation of the energy density (i.e. capacity per weight) of batteries, which turns in the variation of the weight per battery pack.

As shown in **Figure 29**, increased energy density may correspond to lower weight per unit and thus lower POM and waste volumes of LMT batteries, even though the difference compared to the MDS scenario is never exceeding 11 percentage points. Contrary to the variation of the lifetimes, main differences are visible in a long term, when more LMT products will enter into the European market (and hence waste batteries will be AfC).

In this case, the corresponding PAfC target is not much affected by the variation of the energy density of batteries in time. In fact, variation for LMT batteries is only a few percentage points between the scenarios with lowest and highest values of energy density (focusing on 2025, 110%-115% in case of excluding e-motorcycles, compared to 113% of the MDS scenario; and 139%-143% in case of including e-motorcycles, compared to 140% of the MDS scenario).

Figure 29: Tonnage waste batteries in 2020, 2030 and 2040 in Europe varying the energy density of batteries

Overall, from obtained results it emerged that the most relevant parameter for the increase/decrease of POM and waste volumes is the market development of LMT products in future units sold. Uncertainty remains high due to the fact that this is an emerging market and still very few data are available to obtain robust results.

4 Initial proposal for an AfC methodology

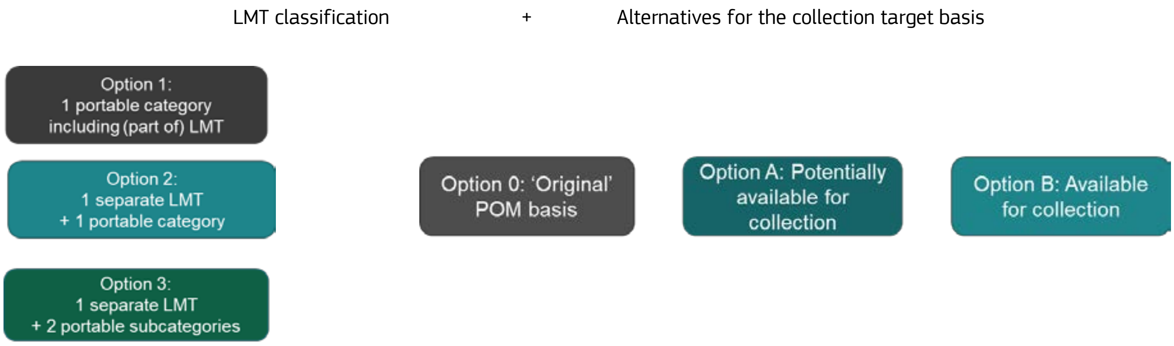
4.1 LMT classification versus the collection target basis

In this Chapter 4, the options for alternative definitions of the collection target are evaluated, also in light of the results presented in Chapter 3. The analysis follows the same structured approach highlighted in Section 1.4. As indicated in Sections 1.2 and 1.4, the need for the collection target alternatives is highly dependent on the choices for the battery categorisation, as already discussed in Section 2.6.

— What would be the need for an alternative collection target for the different LMT category definition options?

Before specifying in detail the alternative collection target bases in the next section, first the consequences of the categorisation and the market analysis are made explicit.

Figure 30: LMT classification versus collection target basis alternatives



Option 1:

In case the bulk of products like e-bikes and e-mopeds are included with portable batteries as recommended with option 1C in particular, the currently proposed POM target basis would be already misaligned due to large new quantities placed-on-market becoming waste much later as demonstrated in Section 3.5. In the best case, the proposed POM target would predominantly be misaligned in time: meaning that the 65% POM level for 2025 would be more ambitious than the 70% in later years. This is regarded problematic as it basically leaves collection schemes without much reaction time to implement collection enhancing measures.

Option 2:

In case the bulk of e-bikes and e-mopeds are classified as LMT, as recommended in option 2C, recent high new market inputs make it practically impossible to achieve POM based collection targets for the LMT category when singled out with an individual target. In the best case here, as a minimum, a AfC approach needs to be adopted for this category which deviates from the POM based target for the remaining portable categories in case this would be kept. Phrased positively, an alternative AfC based target would result in more emphasis on organizing a dedicated collection channel and efforts towards the collectors of LMT batteries to establish a monitoring of the waste flows in order to meet an individual target. In this case, higher LMT collection volumes and improved monitoring are expected for these 'more' relevant battery types, as well as improved focus on safety in handling and recycling.

Option 3:

Option 3 aligns best with an AfC approach in case 3 (sub)categories are selected. This option would take full benefit of an alternative collection target basis definition since the collection target would need to be achieved individually. In simple words: a relatively high collection of alkaline batteries could not disguise lower collection rates for lithium batteries which are relatively speaking more environmentally relevant per ton collected. Another advantage might be that any significant changes in the ratio of primary versus rechargeable batteries, for instance from improved durability requirements, could be corrected for.

4.2 Options for defining the collection target for portable and LMT batteries

5 Collection target basis

The next key question is:

— What are alternatives for the collection target basis?

An overview of options for the target is presented in table 12. Purposely, all possibilities for formulating a collection target basis are presented for the sake of completeness of the analysis.

Table 12: Options for the collection target basis.

Name	Definitions	Methodology requirements
Option 0: 'Original' POM basis	Current proposal, e.g. 70% of average of 3 preceding yrs.	Business as usual. For all options, a reliable reporting needed for POM and Collected volumes
Option A: Potentially available for collection	PAfC = POM x lifespan distribution e.g. y% of Potentially Available for Collection	Conversion of average lifespan to distributed lifespan (per subcategory). Curve fitting needed to convert lifespan to Weibull or normal distribution parameters. For some categories (temporary) assumptions (f.i. missing data, representativeness, asymmetry in the distribution curve). For some batteries in WEEE, the same lifespan from the WEEE common methodology tools can be used.
Option B: Available for collection	AfC = PAfC - deduction	Same basis and lifespan information as PAfC, but with deductions. Theoretically, 4 complementary flows could be deducted: batteries in EEE exported for reuse, batteries in long term hoarding, batteries remaining in residual waste and (not removed from WEEE).
Suboption 1: Deduction tonnage	B1: (tonnage deduction based on reporting), e.g. y% of (tons PAfC – reported export)	Structural reporting of export reuse and long-term hoarding required: The tonnage of batteries in export for reuse can be deducted from POM (i) or reported as collected (reuse volume) (ii). Long-term hoarding of batteries can be included in the lifespan profile.
Suboption 2: Deduction %	B2: (% based deduction from research studies), e.g. y% of (PAfC% – z% for flows not collectable)	But structural reporting of batteries 'not removable' from WEEE and residual waste needed: **A percentage of batteries that can not be collected due to export for reuse, long-term hoarding, not to be prevented from residual waste, or not removable from WEEE to be estimated based on complimentary flow studies.**
Option C: A first, B later	See option A and B	See above. Decision on the final collection target basis after research and monitoring progress made over several years.
Option D 'No loss policy'	Similar to industrial and EV batteries	Potentially applicable to the **LMT** (sub)category.

It is important to distinguish here the target basis with its definitions and subsequent methodological requirements from the decision on the target level that will be discussed later in Section 4.4.
- Option 0 represents the current proposal based on sales of batteries in three preceding years, with a target level now of 45% of placed on market in three preceding years, respectively 65% in 2025 and 70% in 2030.
- Option A represents an approach similar to the WEEE Generated one in the WEEE Directive (Magalini et al., 2016; European Commission, 2017), where the past market input is multiplied with a lifespan distribution. Important to note here, is that the type of distribution function can be different, depending on the need for a simple function or a more advanced one that takes into account the need to correct for 'asymmetrical' discarding behaviour of consumers or not. In any case, some grouping of battery products with similar lifespans and weights is needed to compute a more realistic waste potential in this case.
- Option B fully relies on Option A, but with the additional possibility to deduct batteries that cannot be collected. Non collectable batteries, which is not defined as a term, are primarily 'lost' in 3 complementary flows, being batteries in exported products (for reuse), batteries in residual waste and batteries not removed (or not reported to be removed) at WEEE treatment. Additionally, long term hoarding may lead to a net accumulation, especially for certain batteries with a high value. Although, technically these batteries are not considered as 'lost', the delay may constitute a substantial amount not available for more immediate collection. Two sub options present two different approaches for deduction of non-collectable quantities:

B1: Deducting **tonnages** reported as export for reuse based on structural monitoring of these flows. Secondly, long-term hoarding can be accounted for in the lifespan profile.

B2: Deducting a 'flat-rate' representing a **percentage** of batteries that cannot be collected due to the two aforementioned complimentary flows plus a certain amount of batteries remaining in residual waste and/or after WEEE treatment (despite consumer awareness efforts and achieving WEEE treatment standards).

Option B1 can be based more on structural monitoring of the complimentary flows involved, whereas option B2 would rely more on regular complementary flow research studies.

- Option C represents developing Option A first without any deductions and Option B later to provide more time to PRO's to arrange for the necessary monitoring and/or research efforts to substantiate the deduction levels as well as gathering of sufficient information for definition of the lifespan options.

- Option D finally represent the 'no loss' option as applicable to EV and Industrial batteries meaning a 100% collection rate of all batteries becoming waste. This may be an option in case a separate collection category is defined.

6 Collection target alternatives

4.3 Options for defining the collection target basis

— What are the pro's and con's of the alternative collection target bases?

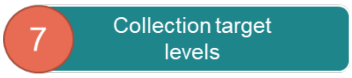
Table 13 below present the various advantages and disadvantages of the collection target basis alternatives.

Table 13: Advantages and disadvantages of the collection target basis alternatives

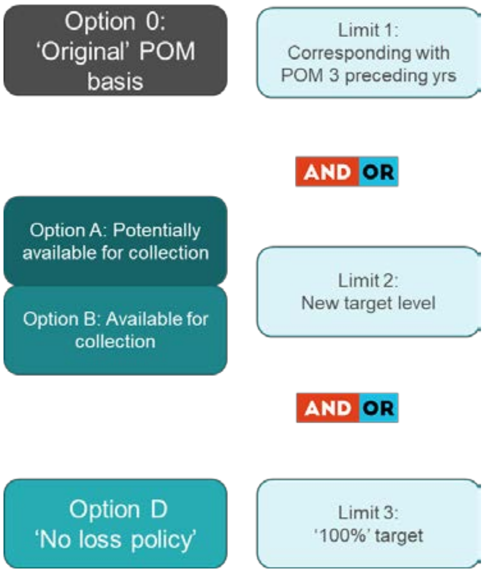
Name	Pro's	Con's
Option 0: 'Original' POM basis	Simple and straightforward	Does not reflect actual waste generation amounts, the actual collection level to be achieved may represent very different ambition levels depending on future market fluctuations.
Option A: Potentially available for collection	Similar to WEEE approach, reflects actual collection potential	Requires more sophistication and definition subclasses
Option B: Available for collection	Reflects actual 'collectable' volumes, incentivizes research into complementary flows	Idem to A. + 'Not collectable' needs to be defined. Data might be very member state specific.
Suboption B1: Deduction tonnage	Export batteries for reuse can easily be deducted when monitored. Hoarding is technically not a loss, can be reflected in the lifespan.	Requires time and effort to report export for reuse
Suboption B2: Deduction %	Deduction based on % representing all 4 main types of 'losses' requires less continuous monitoring effort.	Deduction may remove incentives to capture complementary flows involved. Approach would be more research based rather than monitoring based as in option B1.
Option C: A first, B later	See option A and B	Allows development time for more detailed monitoring of flows. However, option B1 practically delivers the same result.
Option D 'No loss policy'	Similar to the approach for EV and Industrial batteries	Despite 'full' efforts, 100% collection of portable and LMT batteries not realistic, risk of overlaps declaring collected LMT batteries as portable ones

Based on this table, the recommended option and most coherent alternative for the POM target basis is Option B1. In this case, the issue of an unpredictable market developed is mitigated and at the same time, no collection disincentives are created which would be the case for option B2. Obviously, the development of a common methodology similar to the WEEE Generated approach may be needed, targeted to relevant classes of batteries that need to be described in terms of lifespan and average weight parameters. Notably, the feasibility of such a methodology is important: In the next Chapter 5.2.1 more information on the required level of detail and data availability will be provided. Nevertheless, an important interim conclusion here is that an AfC based approach relatively speaking, will function better than a POM based approach in case the market is more and more dynamic. As long as market input is registered well by the PRO's, which is currently more the case than when drafting the WEEE Generated approach for electronics at the time, the AfC is a much fairer starting point for collection efforts that the original POM basis.

4.4 Options for defining the collection target levels



— What are corresponding target levels for the alternatives?

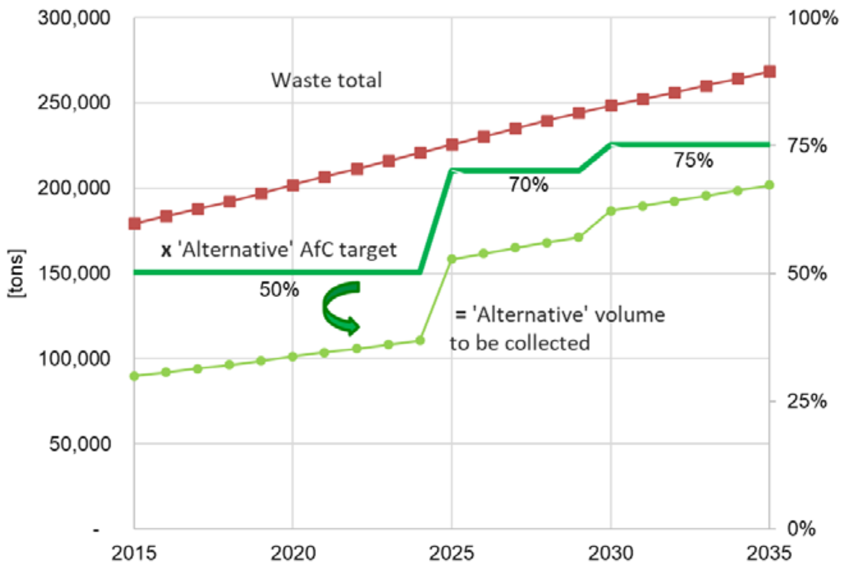


In principle, the choice for the collection target level is a political decision, ideally representing an achievable environmental ambition. Three different options exist which are partially related to the choice of the collection target basis: In the cases of maintaining the POM collection target basis, obviously no new level is needed, assuming LMT batteries would be collected at equal levels as portable batteries for the purpose of this research. For the 'no loss policy', obviously, the target level automatically is 100%.

However, for the recommended AfC approaches, the original POM level does not apply one to one anymore. Two options remain in this instance. An entirely new level can be chosen, or, based on the market assessment of Chapter 3, a corresponding level for AfC can be computed for original respective 45%, 65% and 70% levels for the total tonnages of LMT, portable rechargeable and primary batteries together. Assuming one and the same level is chosen for the 3 (sub)categories, obviously the corresponding individual tonnages will not be similar to the POM approach, especially for the LMT products.

It is recommended in this study, to aim for the first option of determining the corresponding level. Now, the challenge is to determine a collection level based on AfC that matches as closely as possible to the original target for the total quantities to be collected for all batteries in scope for both option 1 as well as option 2 plus 3. In annex 8 by using the MS Excel solver, the closest match is computed by adding x % to the original 45%, resp. 65% and 70% levels and multiplying that 'alternative' level with the AfC volumes. It is computed that **for the period 2023 – 2035**, for the MDS scenario, the same collection volume would have to be collected when the **x = +5.3%.** In short this means that the POM based target needs to be increased by 5% to basically match the original ambition of the proposed Regulation. When applying this +5% level, the 'to be collected volumes' for each of the three subcategories Primary, Rechargeable and LMT reflect the actual volume available in a much more realistic manner, especially for LMT batteries. For further details in tons, see Annex 8.

Figure 31: 'Alternative' AfC target levels corresponding with the 'originally' proposed POM-3 yrs ambition for the same collection volume between 2023 and 2035



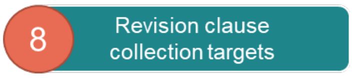
From the analysis of Chapter 3, for the MDS scenario, this would mean that 65% of 3 years preceding POM, would correspond with **70% of AfC** and 70% of POM 3 preceding years with roughly **75% of AfC**. Important to note is that in case of applying these corresponding percentages, the collection objectives now remain consistently ambitious over time, contrary to the original POM basis, while for the period 2023 – 2035 targeting the same total collection volume of 2.2 million tons (see Annex 8 for all values).

In case of the LDS and HDS scenario for LMT batteries, the values for the x% addition are respectively +4.6% and +5.2%. This illustrates the sensitivity of the calculation for these possible scenarios. When the primary and rechargeable batteries simultaneously also follow an LDS and HDS scenario, these difference in the target level for 2023 – 2035 would be +2.4% and +6.1% respectively. This basically means that the POM$_{3years}$ target currently set at 70% for 2030 effectively requires collection of 72% of AfC in case market growth stalls (LDS), or reversely, 76% of AfC in case the growth further accelerates. In simple terms, depending on the market evolution, the POM$_{3\ years}$ approach may represent a different ambition level. This disadvantage would not apply in case of an AfC approach. The quantification of these scenarios are available in Annex 8.

This study does not analyse the market scenarios on a member state level. However, different market uptake levels of LMT products are observed. A similar effect of different ambition levels likely appears as well. ‘Early adopting countries’ with a significant fleet of LMT products already will likewise have a less challenging collection target in comparison to countries which adopt later and faster. Thus, between countries individually, the POM based target may represent different ambition levels.

In case option 2 or 3 are selected, it may be needed eventually to arrange for the possibility to adapt individual collection target levels at a later stage as part of a revision process.

4.5 Needs for revision clauses/ updates



— Would a revision clause for collection target basis be needed?

Depending on the choices made above, different needs for an eventual revision may be required, in particular for the development and/or update of a common methodology, as well as for setting appropriate collection target levels in case of individual ones per collection (sub)category.

- For Option 0: in case the original POM target definition remains the same, there would be no need for a revision clause, nor update according to scientific and technical progress.

- For option A: Depending on the development of a common methodology specifying AfC, a revision clause or update possibility in case of an implementing act is recommended in order to substantiate decisions on the subclasses required for calculation, the lifespan distribution type and lifespan values in case changing over time, which is rather likely to improve for LMT batteries in particular.

- For option B, this would be similar to option A, plus, a technical update may be required to update the calculation rules to address long term hoarding/ in the lifespan parameters in case of option B1. For option B2, it will be uncertain how reliable complementary flow information will be for amounts to be deducted. The approach may not be feasible/ not leading to desired collection improving incentives, which in case selected, most certainly requires a revision possibility.

- For option C, revision needs are the same as for option B1.

- For Option D, there would be no need for a revision in case solely applied to the LMT category alike the EV category.

4.6 Evaluation of option combinations

Based on the analysis in this chapter, the following options are advised, grouping the most logic combinations from the Sections 4.2 – 4.5 for the collection target definition. For all three categorisation options, but surely for the Option 2 and 3, a redefinition of the collection target based on AfC is recommended. For option 1, the suboption 1B is recommended, as it includes the possibility to deduct quantities reported as exported for reuse later, in case monitoring of this complimentary flow is advancing. Possibly, long-term hoarding leading to a net accumulation can be corrected for in the lifespan function. For all three options, when maintaining the original ambition level related to 45% from adoption of the Regulation and 65% of POM in 2025 and 70% in 2030, the corresponding levels for a target based on AfC would be respectively **50%** of AfC at adoption, **70%** of AfC in 2025 and **75%** of AfC in 2030. Some specificities for the categorisation options are added in this overview:

Option 1:
1 portable category
including (part of) LMT

- The collection target to be converted to AfC, preferably directly upon adoption of the Regulation, with the possibility at Member State level to deduct batteries that are monitored as leaving the national territory (for reuse/ remanufacturing).
- A **single** corresponding target level (suggested is 50% at adoption, 70% of AfC in 2025 and 75% of AfC respectively in 2030)
- A common methodology needs to be developed with certain number of product classes to be determined to reflect the different lifespans of the subcategories of primary, rechargeable and LMT products. Possibly, a lifespan correction can be included for those battery types with a net long-term hoarding.
- A revision clause is deemed not to be necessary in this case.

Option 2:
1 separate LMT
+ 1 portable category

- Idem as Option 1, with **two** identical AfC based collection targets,
- With 50% of AfC at adoption, 70% of AfC in 2025 and 75% of AfC respectively in 2030,
- With a revision clause to adapt the **two** individual collection target according to realised collection results and environmental priorities.

Option 3:
1 separate LMT
+ 2 portable subcategories

- Idem as Option 2, with **three** AfC based targets to be achieved for LMT and the two portable subcategories primary and rechargeable,
- with 50% of AfC at adoption, 70% of AfC in 2025 and 75% of AfC respectively in 2030
- Additionally, individual monitoring and reporting of collection volumes of primary and rechargeable to be established
- With a revision clause to adapt the **three** individual collection target according to realised collection results and environmental priorities.

Depending on legislative decisions, the following articles to the collection rate may require a revision: In **Article 46** related to the register of producers, LMT batteries are not (yet) mentioned. **Article 48** currently only refers to portable batteries and, amongst others, for instance does not (yet) address specific collection points related to LMT batteries. **Article 55** explicitly does not (yet) include a collection target for LMT batteries. Finally, in case option 2 or 3 is selected, **Article 61** on the reporting of collection performance to authorities possibly needs an explicit mentioning of a new categorisation.

5 Conclusions and recommendations

5.1 Conclusions of the study

— Is there a need to revise the collection target?

From the comparison between the POM_{3years} target with the AfC approach, the main conclusion is that there is indeed a need for an alternative target to compensate for the time-discrepancy of the first that may result in more and less challenging collection volumes than intended over time. Based on the analysis in previous chapters, modernising the collection target basis is deemed **feasible and beneficial** in anticipation of highly uncertain future waste amounts. This cannot be addressed if the review of the targets and methodology takes too long. This conclusion is drawn regardless of considerations to adapt the categorisation: due to increasing sales of rechargeable and LMT batteries, as well as potentially more durable primary batteries, there is a growing discrepancy between the POM volumes and the waste volume becoming available later. Adopting a POM based target for waste LMT batteries could become very challenging in the years 2025 and 2030 when the newer target levels of 65% respectively 70% are to be achieved and relatively speaking low in later years. This may allow ample development time for collection schemes to implement collection enhancing measures.

For all portable and LMT batteries together, the currently proposed POM based target, is relatively speaking high in the years 2025 and 2030 when the originally proposed target levels are respectively increased to 65% and 70% and relatively speaking low the years following. This may allow ample development time for collection schemes to implement collection enhancing measures. In case a separate collection category for LMT batteries is adopted, it is inevitable to adapt the collection target basis to correct for increasing battery volumes with longer lifespans.

In simple terms, **the more dynamic the future market** of LMT and portable batteries will be, with more longer lasting batteries, **the more reason to consider an AfC based collection target** as recommended for all three categorisation options below.

— Is there a need to revise the categorisation of LMT batteries?

A decision to create a separate LMT category has additional consequences related to other requirements in the legislative proposal as well and a range of advantages and disadvantages. Certainly, one of the advantages is that with an **in-between** category, these other requirements like, for example, the information elements of Article 13 and the repair and remanufacturing possibilities related to Article 14 and Article 59, may be better fine-tuned for the specific (future) characteristics of LMT products. Technical assessment of other sustainability and durability requirement of the proposal are out of scope and mandate of this study. Hence, no final recommendation is provided for option 1, 2 or 3.

— How to align the collection target for the three categorisation options?

Option 1:
1 portable category
including (part of) LMT

In case of no separate LMT category, the LMT products still need to be divided between the portable and EV categories. Based on the analysis of Chapter 2, in order for the lighter products to fit in the portable category, it is hence recommended to split in such a way that the bulk of batteries from e-bikes and lower weight than 8 kg (roughly equivalent to 2 kWh) are included with portable batteries. Once they become waste, LMT batteries would be subject to the proposed targets for portable batteries. No revision clause would be needed for the categorisation in this case at a later stage.

Option 2:
1 separate LMT
+ 1 portable category

From a collection target and thus environmental ambition perspective, the options 2 and 3 as presented below are regarded favourable from a 'collection enhancing' point of view. In case a collection target for LMT batteries is not postponed, there can be more immediate attention to establishing more collection points for instance with bicycle and scooter dealers and other incentives to improve collection early on. Moreover, stakeholders highlighted that different handling and safety requirements should apply for larger LMT batteries. In several Member States, collection channels are being adapted already to account for this, or are in the process of creating dedicated PRO's and contracts with collection points.

Based on the analysis of market scenario developments in Chapter 3, both the market amounts and characteristics of the portable and LMT batteries will change significantly in the coming decade. With the aforementioned increasing time between placing on the market and discarding as waste, the limits of the POM based approach could be reached soon. The POM based target level simply does not represent a similar collection level and thus environmental ambition in case the market increases or decreases. Especially for LMT batteries, collection levels close to, or above a 100% are likely to appear, meaning that desired collection volumes can only be achieved by cross-subsidising via collecting other batteries to achieve an individual LMT target.

Although the scope of the present assessment is on the EU market as a whole, at Member State level this time discrepancy is expected to be even larger. For those countries where LMT products are relatively new and the anticipated bulk of longer lasting products still has to appear on their national market, the POM based collection volume to be achieved versus the waste volume potentially available will become even more of a mismatch in future years.

For both 'Option 2' and 'Option 3' with both a new fifth category for LMT, some additional administrative burden is expected related to more monitoring and reporting efforts. However, in case of adopting an AfC based approach, the collection schemes indicated willingness to develop the required monitoring and reporting procedures timely. They also indicated support for additional research to substantiate the parameters to establish a common methodology based on AfC.

Option 3:
1 separate LMT
+ 2 portable subcategories

Option 3 would take full benefit of an alternative collection target basis definition since the collection target would need to be achieved individually. In simple words: a relatively high collection of alkaline batteries could not disguise lower collection rates for rechargeable lithium batteries anymore. Another advantage might be that any significant changes in the ratio of primary versus rechargeable batteries, for instance from improved durability requirements, could be corrected for. At the moment, the actual collection rates for the two subcategories individually are not well-understood, which complicates a substantiated choice for an individual target level and thus the feasibility of an eventual individual target unclear at the moment.

In case an alternative AfC based target is selected, it is expected to result in more emphasis on organizing a dedicated collection channel and efforts towards the collectors of LMT batteries to establish monitoring of the waste flows in order to meet an individual target. In this case, higher LMT collection volumes and improved monitoring are expected for these 'environmentally more relevant' battery types, as well as improved focus on safety in handling and recycling. Another constraint to this option will likely be increased monitoring and report efforts and possibly additional sorting costs. Assessment of additional costs and administrative burden are out of scope of this study.

It is therefore recommend to start with Option 2 as a 'future-proof' choice that may enable Option 3 with differentiated monitoring and reporting of primary versus rechargeable batteries later. This choice for option 2 now would form a basis for later deduction of non-collectable volumes, like batteries exported for reuse (with WEEE) and provide the necessary time to improve related monitoring and reporting procedures. A review clause might be needed to adjust of the collection target levels and the common methodology according to technical progress and to evaluate the other administrative and economic impacts of option 3 when considered later.

5.2 Technical recommendations and next steps

— How to develop a common methodology based on AfC?

In case the AfC option is considered in the current legislative process, the market assessment and stakeholder feedback provided during this study already does constitute a sufficient analytical basis for developing a common methodology for the calculation rules for an AfC alternative.
Obviously, the lifespan parameter for the 'waste distribution curve' is the most crucial parameter to be assessed. This study focused on the EU market as a whole. In case substantial differences are expected between Member States, then more detailed assessment of lifespans of batteries for a select number of countries might be needed. To be noted is that although there is significant discussion possible about the sensitivity of the results in relation to the (assumed) lifespan, the actual uncertainty is not too high. In simple terms: for long lived products like e-bikes, the effect of a difference between 9, 10 or 11 years of age is much less than the current implicit assumption of sales in 3 preceding years.

Article 48(12) already specifies a provision to conduct compositional analysis for portable batteries in WEEE and Municipal Solid Waste (MSW). Stakeholders suggested to include additional provisions in the proposal to substantiate an AfC methodology and the associated reporting. Here, specific gathering of age distribution information for all relevant complementary flows may well support the gathering of reliable parameters, being lifespan distribution, number of units per battery type and weight distribution per item, on a Member State level. It should be noted that during the workshops there was broad consensus, willingness and confidence among the industry stakeholders and PRO's to research and timely deliver (before 2023) the required technical documentation to substantiate an eventual common methodology.

One valid concern raised in the technical consultation is that the common methodology should not become overcomplicated. In the case of the WEEE Directive which is a much more heterogeneous waste stream, 54 'UNU keys' are used in the common methodology and the tools for Member States. With WEEE registers data relatively incomplete at the time of development (Magalini et al., 2016), the WEEE approach relied on trade statistics, whereas in the case of batteries, national registers data should be the starting point, which likely should simplify the approach. From an analytical point of view, the more subclasses of batteries can be specified, the more reliable determining the lifespan behaviour can be. However, more detailed product data limits the availability of such information at the same time. Therefore, a meaningful grouping of products with similar weights and lifespans could be chosen for the development of a common methodology in the case of batteries. Further aggregation and simplification is possible in case the 'baskets of battery products' investigated remain rather similar over time.

In the case of a batteries AfC approach, a much lower number of classes are foreseen compared to the WEEE Generated approach (European Commission, 2017) as a significant aggregation into a limited number of classes seems achievable. Another complication mentioned is that a Weibull distribution function is more difficult to explain to non-statisticians. Also here, for batteries, dependent on the level of 'asymmetry' in the discarding behaviour, 'simpler' distribution functions shall be considered like a 'time delay' or 'normal distribution' function. Based on previous experience, knowing data needs early on and **prior to** conducting possession surveys, will potentially save valuable time in later data analysis and prevent unnecessary levels of details in costly surveys and sampling efforts.

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List of abbreviations

ADR	European Agreements on the international transport of dangerous goods by road (ADR)
CAGR	Compound annual growth rate
DG	Directorate General
ELV	End-of-Life Vehicles
EPAC	Electrically Pedal Assisted Cycles
EPR	Extender Producer Responsibility
EU	European Commission
EV	Electric Vehicles
HDS	High Demand Scenario
HEV	Hybrid Electric vehicles
JRC	Joint Research Centre
LDS	Low Demand Scenario
LFP	lithium iron phosphate
LIB	Li-ion battery
LMT	Light Means of Transport
MDS	Medium Demand Scenario
NCA	Lithium Nickel Cobalt Aluminum oxide
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
NMC	Lithium Nickel Cobalt Manganese oxide
(P)AfC	(Potential) Available for Collection
PbA	Lead Acid
PHEV	Plug-in Hybrid Electric Vehicles
PLEV	Personal Light Electric Vehicles
POM	Placed on the Market
PRO	Producer Responsibility Organizations
(W)EEE	(Waste from) Electrical and Electronic Equipment

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Annex 1. Research classification of batteries used of the JRC Battery Raw Materials Model

Nr	Code _short	Chemistry	Application family	with data?	Main source/ first use
1	LCOportablePC	LCO	Portable - rechargeable	Y	ProSUM/ ORAMA
2	LCOcellphones	LCO	Portable - rechargeable	Y	ProSUM/ ORAMA
3	LCOcamerasgames	LCO	Portable - rechargeable	Y	ProSUM/ ORAMA
4	LCOebikes	LCO	LMT	Y	Merged into 24_ebikes
5	LCOindustrial	LCO	Industrial	Y	ProSUM/ ORAMA
6	LCOtablets	LCO	Portable - rechargeable	Y	ProSUM/ ORAMA
7	LFPothersportable	LFP	Portable - rechargeable	Y	ProSUM/ ORAMA
8	LFPebikes	LFP	LMT	Y	Merged into 24_ebikes
9	LFPIndustrial	LFP	Industrial	Y	ProSUM/ ORAMA
10	LMOcamerasgames	LMO	Portable - rechargeable	Y	ProSUM/ ORAMA
11	LMOothersportable	LMO	Portable - rechargeable	Y	ProSUM/ ORAMA
12	LMOebikes	LMO	LMT	Y	Merged into 24_ebikes
13	LMOPHEV	LMO	Portable - rechargeable	Y	SASLAB/ JRC
14	LMOBEV	LMO	Portable - rechargeable	Y	SASLAB/ JRC
15	LMOindustrial	LMO	Industrial	Y	ProSUM/ ORAMA
16	LMOprimary			N	Not in use, merged in 59_Liprimary
17	LCFprimary			N	Not in use, merged in 59_Liprimary
18	NMCportablePC	NMC	Portable - rechargeable	Y	ProSUM/ ORAMA
19	NMCtablets	NMC	Portable - rechargeable	Y	ProSUM/ ORAMA
20	NMCcellphones	NMC	Portable - rechargeable	Y	ProSUM/ ORAMA
21	NMCcamerasgames	NMC	Portable - rechargeable	Y	ProSUM/ ORAMA
22	NMCcordlesstools	NMC	Portable - rechargeable	Y	ProSUM/ ORAMA
23	NMCothersportable	NMC	Portable - rechargeable	Y	ProSUM/ ORAMA
24	ebikes	Li-ion chem. mix +PbA	LMT	Y	Merger from individual keys
25	NMCHEV	NMC	Portable - rechargeable	Y	SASLAB/ JRC
26	NMCPHEV	NMC	Portable - rechargeable	Y	SASLAB/ JRC
27	NMCBEV	NMC	Portable - rechargeable	Y	SASLAB/ JRC
28	NMCindustrial	NMC	Industrial	Y	ProSUM/ ORAMA
29	LSOprimary		Portable - rechargeable	N	Not in use, merged in 59_Liprimary
30	LTCprimary		Portable - rechargeable	N	Not in use, merged in 59_Liprimary
31	NiCdcordlesstools	NiCd	Portable - rechargeable	Y	ProSUM/ ORAMA
32	NiCdothersportable	NiCd	Portable - rechargeable	Y	ProSUM/ ORAMA
33	NiCdindustrial	NiCd	Industrial	Y	ProSUM/ ORAMA
34	NiMHportablePC	NiMH	Portable - rechargeable	Y	ProSUM/ ORAMA
35	NiMHcordlesstools	NiMH	Portable - rechargeable	Y	ProSUM/ ORAMA
36	NiMHothersportable	NiMH	Portable - rechargeable	Y	Not in use, w/o data
37	NiMHHEV	NiMH	Portable - rechargeable	Y	SASLAB/ JRC
38	NiMHindustrial	NiMH	Industrial	Y	ProSUM/ ORAMA
39	PbAothersportable	PbA	Portable - rechargeable	Y	ProSUM/ ORAMA
40	PbASLI	PbA	Automotive	Y	ProSUM/ ORAMA
41	PbAebikes	PbA	LMT	Y	Merged into 24_ebikes
42	PbAindustrial	PbA	Industrial	Y	ProSUM/ ORAMA
43	Alkaline	Alkaline	Portable - primary	Y	ProSUM/ ORAMA
44	Otherindustrial	Other	Industrial	Y	ProSUM/ ORAMA
45	Liprimary	Li-ion	Portable - rechargeable	Y	ProSUM/ ORAMA
46	LMOSLI	LMO	Automotive	N	Not in use yet, w/o data
47	NCABEV	NCA	EV	Y	SASLAB/ JRC
48	NCAindustrial	NCA	Industrial	Y	ProSUM/ ORAMA
49	LFPSLI	LFP	Automotive	not yet	Not in use yet, w/o data
50	LFPebus	LFP	EV	Y	JRC update 2021
51	LFPetruck	LFP	EV	Y	JRC update 2021
52	LFSprimary		EV	N	Not in use, merged in 59_Liprimary
53	NMChomeESS	NMC	homeESS	Y	SASLAB/ JRC
54	NCAhomeESS	NCA	homeESS	Y	SASLAB/ JRC

55	LFPhomeESS	LFP	homeESS	Y	SASLAB/ JRC
56	LMOhomeESS	LMO	homeESS	Y	SASLAB/ JRC
57	NCAPHEV	NCA	EV	some	SASLAB/ JRC
58	LMOHEV	LMO	EV	Y	SASLAB/ JRC
59	Otherprimary	Other (non-Li, non-alkaline)	Portable - primary	some	UNITAR/ STIBAT
60	LFPMDV	LFP	EV	some	JRC 2021
61	LFPBEV	LFP	EV	some	JRC 2021
62	LFPPHEV	LFP	EV	some	JRC 2021
63	LFPHEV	LFP	EV	some	JRC 2021
64	LCOhomeESS	LCO	homeESS	some	JRC 2021
65	small PLEV	Li-ion chem. mix	LMT	Y	JRC 2021
66	escooters	Li-ion chem. mix	LMT	Y	JRC 2021
67	emopeds	Li-ion chem. mix	LMT	Y	JRC 2021
68	emotorcycles	Li-ion chem. mix	LMT	Y	JRC 2021
69	maritime	Li-ion chem. mix	Industrial	some	JRC 2021

Sources: Chancerel et al., 2016; Wagner et al., 2019, Huisman et al., 2020

Annex 2. Minutes of the first AfC Workshop (19/03/2021)

Participants:

JRC, DG ENV, BEBAT, Bosch, CONEBI, EPBA - GP Batteries, EUCOBAT, COREPILE, COBAT, LEVA, RECHARGE, EPBA

Summary of the interviews, technical evidences

LEVA

- Regulation could have a negative impact on small businesses, especially in relation to the 2 kWh limit which is very low considering the current market (legal bottleneck for PLEVs) → manufacturers can decide to split batteries in vehicles
- For batteries of PLEVs that fall under the EV battery category, requirements are quite difficult to be respected, especially since this business is linked to realities outside EU, which suppliers are the majority when speaking about batteries
- L-categories are not under the ELV Directive (but under WEEE Directive), while EV batteries are.
- Currently important technical development going on → 2kWh threshold is really a problem. For instance for e-cargo bikes, 2 kWh limit make them absolutely not interesting anymore, or manufacturers are expected to use more batteries to stay under the limit
- Maybe there is not a good understanding of the e-low vehicles business? Business is today limited compared to EV business but it is fast increasing.

CONEBI

- Within bicycles, you have a variety of vehicles inside the scope of type approval (like EPAC45 higher than 25 km/h) and also e-bikes that fall under the Regulation 168/2013. But batteries for these vehicles are quite similar (similar weight, energy capacity and treated very similar by the producers and these should folder under the same categories → easier for the consumer to dispose correctly these type of batteries and also for the collection scheme it is easy to treat these batteries in a similar way.
- Using the Regulation 168/2013 for the categorization could be quite problematic.

Bosch

- EPAC25s are not covered in the type approval Directive (fall under the WEEE and Machinery Directives) → very much in favour to have a very large and encompassing definition here as use patterns for these batteries are similar
- Separate collection is necessary anyway as LIB are treated as dangerous goods under the ADR → necessity anyway and should be into account
- You should also be looking at using patterns of different LMT → e-bike and EPAC25 (or 45) the usage pattern is of personal use (private ownership); while for e-scooter there is a lot of rental systems. This also has effects on charging patterns and calendar ageing
- For LMT, the POM model is absolutely not reflecting the lifespans of batteries. So that any AfC model will be welcomed for this sector

RECHARGE

- RECHARGE does not see a definition fitting based on weight, capacity or power for all types of batteries; More flexibility could be helpful in defining what is a battery belonging to LMT and portable batteries, as there is no real identifiable fix boundary (e.g. weight can cut products in two sets of products).
- In any case, when users are dealing with the batteries at the end of their use, there is no way today to guarantee that the battery is removed or not by end-user of this type of vehicles. Therefore, it will be a kind of case-by-case if batteries is taken-back or not, and this is not related to the weight (nut contrary on the removability)

- So that probably better to stay with the current definition, stating (instead of a weight limit) "hand-carried"[16]

COBAT

- Remark on mono-wheels and e-steps: these kind on PLEVs could be included in LMT definition (today excluded), as the collection of batteries is very similar to other LMT batteries
- The specification "*on which travellers are seated*" should be eliminated

DG ENV

- Requirements for sustainability only apply to the larger batteries for reasons of proportionality and effectiveness, and then a first approximation is a capacity threshold. Ok, there is not much support for this capacity threshold, but also for classification based on type-approval of vehicles.
- Question to industries is: what can you advice (as elegant and future proof) classification of batteries to identify the larger batteries (which will follow under the sustainability requirements)?
- Keep mind that right now, LMT are part of the portable batteries and not EVs and the sustainability requirements for EV batteries do not apply.
- The "can be carried" will not be considered since Member States want clarity (no flexibility), no overlap, no gap, easy to work and easy to implement

RECHARGE

- Suggestion is the adoption of 2 limits between portables and industrial batteries, not only 1.
  - One limit is portable from industrial (which is linked to collection target), and a limit as clear and simple as "weight" is not possible
  - Question of the fate of batteries that are small portable (i.e. under the 2kWh limit).
- More complex and ambitious sustainability requirements (in particular for audited requirements) should apply only to EV batteries or large ESS (energy storage system) batteries. The suggested boundary is more than 20 kWh

L1 and L2 with LMT and L3 and higher with N,M categories?

LEVA

- In favour of a very clear legislation which excludes all batteries for PLEV of the L-category from the EV batteries requirements, as the 2kWh limit is going to cause un-clarity and unwanted consequences and it will slow the transition from ICE (internal combustion engine) to electric (mopeds, motorcycles)
- The 2kWh limit will leave out a market with a very big potential
- Also self-balancing vehicles are not included in the type-approval, together with mono-wheels and e-scooters.

CONEBI

- Portable batteries: 5 kg limit is quite problematic aspect, especially for future-proof regulation. We will move beyond very soon
- LMT: the 250 W limit for EPAC25 seems a bit arbitrate, as a for a Regulation dealing with batteries, a capacity limit should be adopted and not a power limit for the engine

BEBAT:

- For BEBAT, the 5 kg limit of portable batteries is really the maximum for the collection. 8 or 9 kg batteries will be really problematic in regarding to the collection rate that are mentioned now in

[16] Article 3 of the Batteries Directive (*'portable battery or accumulator' means any battery, button cell, battery pack or accumulator that:*
(a) is sealed; and
(b) can be hand-carried; and
(c) is neither an industrial battery or accumulator nor an automotive battery or accumulator;

the Regulation → increasing the weight to 8 or 9 kg is not the solution. Maybe a solution is to create a separate category?

- Producers of such batteries have to declare to the compliant organisations and it's now already very difficult to declare the chemistry composition and the weight of the battery

Bosch

- E-bikes are nowadays considered industrial batteries and the problem is not only related to how users handle their EoL (end-of-life).
- Majority of e-bikes in the EU streets has e-packs 25 which is not considered in this table and a not covered by the Regulation 168/2013
- In favour of a change and definition of LMT

Results of an initial calculation run comparing POM vs AfC

JRC

- The shown calculation run is to be used as an example. The POM data is aligned with the Impact Assessment baseline, with longer lifespans than previous Mobius/Eucobat/ProSUM project assessments. Further sensitivity analysis will be done, in particularly evaluating the influence of lifespans and LMT forecasted quantities in the future.
- GP asked for the data for portable rechargeable + single use minus the LMT data. JRC promised to provide this. It can also be computed from the difference between the totals and LMT only numbers demonstrated.

Technical discussion of the feasibility of an alternative methodology

DG ENV

- Recyclers will never accept to have an amount of batteries collected (and recycled) lower than the current value.
- Do you select the methodology before or the target before? In 2006, the choice was first the target and then methodology. Now, the Commission is trying to adopt in parallel both the target and the methodology, but this need to carefully consider pros and cons.

RECHARGE

- More precise calculations are more complex and it requires more data. But we need to understand what is needed to achieve to decide the most suitable methodology.

GP batteries

- In reality, 3 years is not applicable as many batteries are not available. Still, there are not enough data to substantiate why 55% of batteries are not collected (simply disappearing from the market, or are there other reasons?)
- Industry is willing to recycle all batteries collected, but we have to look into the flows that are disappearing/not available for collection
- EPBA is in favour of more ambitious collection and recycling targets
- A transition to move from a POM model to AfC is needed, and PAfC could be considered the a transitional target

RECHARGE

- New regulation is the opportunity to achieve better traceability of batteries
- With more information, we are in a better position to go towards AfC or PAfC in the future

BEBAT

- The WEEE flow has the same problem as batteries flows. Is there a possibility to have a registration obligation about tracing this waste stream in the future?

DG ENV

- Transboundary movement should be considered in the Regulation and traceability of batteries is a good example for improving the system.
- In the question of data generation, in the proposal PROs are asked to do compositional studies on municipal waste and WEEE streams. These are obligations (copied from Belgium); there will be some difficulties but still to be seen this will be finally maintained, but is the idea to generate data, to allow collectors to target, to intensify the activity.

LEVA

- Any PLEV under the L-category excluded from type approval come under WEEE), so a lot of practical problems will arise in registration

GP batteries

- Based on Article 55 ("*Collection rates for waste portable batteries*"): if we agree that the AfC is the most viable option, would it be possible from 2024 to have an alternative model to move towards AfC model, based on data collected and a further analysis?
- So that you can set the target based on the data and information that are currently un-available

DG ENV

- The 45% target was a catch of the 2022 situation. The last mandatory value in the Directive was put as first value of the Regulation. 45% is only a bridge towards the new Regulation.
- Risk of a very long and complex discussion about quality and availability of information/data

RECHARGE

- There is a common need of more transparency of the flows to have better capability for calculations and reduce illegal flows.
- The only difference is only on the assessment of EoL (end-of-life) flows, which includes the legal and illegal aspects. What makes the difference between AfC and PAfC? Is it possible to recognize illegal/un-controllable export?
- Will it be possible to have a clear understanding on batteries embedded in EEE/WEEE and related transboundary movements? If we have enough information available we can move directly towards the AfC method

BEBAT

- It is true that data are not available but, on the other hand, high collection rates are there and batteries not AfC have to be collected.

RECHARGE

- Today there is a need of more transparency and accuracy of collection business; in all these contexts, it seems that taking some risks of the future availability of data in a world moving to digitization (big data) is not really un-achievable.

Annex 3. Minutes and feedbacks from the second AfC Workshop (19/05/2021)

Involved stakeholders:

BEBAT, Bosch, CONEBI, EPBA - GP Batteries, EUCOBAT, COREPILE, COBAT, LEVA, RECHARGE, EPBA, ACEM, EGMF

CONEBI

- Option 1: 1 portable category including (part of) LMT
  - o When presenting "which products with portable vs EV" in Option 1A you highlight iii as the preferred one that would mean all non-type approved vehicles and e-bikes fall within portable and all type approved vehicles within EV or industrial. However, where would type approved EPAC45 fall here?
  - o Overall, we would prefer Option 1B or possibly 1C for defining LMTs to make it future proof as changes in the type approval legislation and other connected legislations are expected.
  - o However, both of these options propose a possible weight limit of 8kg, whereas your proposal does not mention increasing the overall weight limit of the portable batteries category, which is currently set at 5kg. Could you please explain this?
- Option 2: 1 separate LMT + 1 portable category
  - o When presenting "which products to be defined as LMTs" we would like to highlight the need to go for Option B or possibly C as option A would split e-bike batteries for EPAC25 and EPAC45 into two.
  - o For Option B both the preferred lower limit to portable batteries and the upper limit to EVs would be supported by CONEBI.
- Overall, CONEBI prefers to keep e-bike and thus LMT batteries closely connected to portable batteries due to their similar handling. This would be similar to your Option 1 but with an increased weight limit for portable batteries. However, a separate collection scheme and collection target should be in place for LMTs due to their higher energy capacity and longer lifetimes.

LEVA

Comments on presentation 19/05/2021:

- <u>Slide 6</u>: it should be taken into account that the market of LEVs excluded from the L-category consists of more than e-bikes, e-scooters and e-monowheels. This is for instance clear from the table below which includes PLEV-sales per category in France in 2020:

PLEV Type	2019	2020
E-scooters	478,000	640,000
E-hoverboards	82,000	94,000
PLEVs with saddle*	29,000	31,100
Electric skateboards	7,700	5,900
E-monowheels	5,462	7,100
Self-balancing vehicles	2,525	5,200

*Should be categorized as L1e-B mopeds

Perhaps, the different types should be mentioned separately, alternatively the exclusions from the L-category could be used, i.e. self-balancing vehicles and vehicles without a seating position.
We have commented on the numbers in this slide in our previous submission sent on 19 May. However, we have sent those comments in your presentation as a pdf-file that didn't show our additional comments in the slides. Our comments in the PPT were previously sent.
As for the prognosis for e-mopeds and e-motorcycles, that will be highly dependent on the classification of their batteries in future legislation. If their batteries are to be classified as EV-batteries, this market will be decimated.

- Slide 8: the different options do not include the impact of that choice on the LEV-business. Again, any choice resulting in LEV-batteries as EV-batteries will destroy the market.

- Slide 9: Our answers to the questions in this slide are as follows.

Question 1: yes, there are specific safety issues with LEV-batteries. For instance, for transport, most of them are categorized as CLASS 9 - MISCELLANEOUS DANGEROUS GOODS. They are therefore subject to UN rules on testing, packaging and transporting.
Question 2: in our view the question as to whether to choose for a product centric or battery waste centric approach is in this case irrelevant. If EV -batteries are to be considered as batteries in electric vehicles in the M-, N- and O-category, then why could LEV-batteries not be considered as batteries in electric vehicles in the L-category and excluded from the L-category?
Question 3: in our view, ALL LEV-batteries should be defined as Light Electric Vehicle batteries, a category in itself next to portable, industry, automotive and EV -batteries. None of the LEV-batteries should be categorized as portable.
Question 4: Yes, a revision clause would be needed since technical regulations are currently under revision. However, if the LEV-batteries are now linked to the L-category (and its exclusions) a revision clause can be kept very simple. Should a new horizontal Regulation be introduced for LEVs, then the reference to the L-category (and its exclusions) can be simply replaced by a reference to the new Regulation.

- Slide 10: our comments on this table are in the previous PPT sent
- Final remarks:

If a weight limit is to be set, what would be the basis for that limit? In the last JRC-presentation there was mention of a limit of 8 kg and in other slides of 20 kg? What is the rationale for these proposals? EV weigh several hundreds of kilos, so why not set the limit at 100 kg to ensure that all LEV-batteries are kept out of the EV-batteries category?
The question was asked about collection targets and methodology. But how can these be defined if we don't know yet how the batteries will be categorized? That categorization will have a huge impact on the number of batteries coming on the market. Again, if LEV-batteries are categorized as EV-batteries, there will be nothing much to collect.
In any case, we believe that it is clear that application of POM is not an option…

RECHARGE

I would like to underline that we support the approach used here.
While I had no precise opinion before this call, I realize that the creation of a sub-category for the LMT is certainly justified, not only because it corresponds to a different collection approach in the field, but also because it could enable the implementation of meaningful collection targets.
Concerning this definition of the LMT, we consider the high limit is correctly identified in the case of an independent category. The main comment I'd like to reiterate is about the fact that the LMT specific treatment is also justified by the fact that these batteries are handled by end-users, and comes back in the corresponding waste flows (contrary to the industrial batteries). Based on this I would like to reiterate our proposal to add in the definition of the LMT batteries the wording "removable batteries". In all other cases, the LMT batteries should remain in the category of EV or industrial batteries, as their change of category would not be justified by any of the points discussed above.
Concerning the AfC, we also support the approach. We consider that the complexity of the approach could be efficiently managed at the European level, including the representative life time per product category. This would enable the Members-states to apply this calculation in a simple and harmonized way, only importing their national data of PoM and collection in the calculation of collection rate.

EUCOBAT

LMT/LEV category

As you are very well aware, Eucobat is proposing to establish a fifth category named 'light electric vehicle battery (LEV)' which would encompass the light means of transport defined by the Commission, as well as all appliances currently out of the scope of the proposed definition for LMT (i.e., appliances on which the traveller is not seated).

Eucobat proposes that this category could be based on type-approval legislation (L1 and L2 categories) whilst also including batteries of vehicles exempted from type-approval and/or official registration such as e-steps, e-skateboards and hoverboards etc… Moreover, we also propose those batteries to be subject to the same EPR obligations as for portable batteries and to set a separate collection target for LEV batteries, based on the 'Available for Collection' methodology (in line with Articles 47 and 48 of the Commission's proposal).

In light of the many new appliances coming onto the market for e-mobility, a new separate LEV category could definitely pave the way for a future-proof and clear regulatory framework. It would provide a better focus on LEV batteries and enable the optimisation of the collection network, while taking into account the fact that LEV batteries are quite different in terms of size, weight (way heavier than portable batteries) and lifecycle (around 10 years).

Therefore, Eucobat welcomes your presentation which showed that it is necessary to take into account the weight of LMT batteries and their lifecycle, making it difficult to have one portable category which would include light means of transport. It also shows the necessity to develop a new methodology. As such, we strongly support the Option 2 that you have presented on Wednesday, aiming at establishing a separate new LMT/LEV category.

Eucobat also believes the JRC did a very interesting work regarding thresholds and possible limits to define this new category. Currently, based on Eucobat's position, we believe the Option 2A would be relevant to define thresholds according to type approved and non-type approved vehicles. Nonetheless, a battery/waste centric approach is also interesting, hence the reason why Eucobat could be interested in a combination of both those options, allowing to have a reference to type-approved and non-type approved vehicles while also allowing the possibility to set a weight threshold.

In this regard, we would also like to draw your attention on the necessity to keep the threshold of 5kg for the portable battery category, which is a good basis to distinguish and sort portable batteries from the others.

Methodology – Collection

We have been pleased to hear that most of the stakeholders invited to the workshop are in favour of the 'Available for Collection' methodology.

Eucobat would like to stress that the Option B, namely adopting an 'Available for Collection' methodology is definitely the way forward in order to provide a realistic and adapted methodology, fitting with the reality of the market and of the waste streams.

We understand the concerns that might arise from co-legislators regarding the current availability of data. Nonetheless, Eucobat believes it is required to be ambitious, as wished for by the European Commission, to ensure that the Battery Regulation is future-proof and lays out an adequate framework for its collection aspects.

Eucobat underlines that Option B, setting an 'available for collection' methodology, will allow its full development by taking into account all the variables from the start (lifecycle, export of WEEE and second hand EEE), thus also incentivising all actors concerned to provide existing data and produce data, allowing for an ever more realistic representation of waste flows, i.e., actual waste batteries collectable and not collectable. Furthermore, the establishment of this methodology could be very well supported by certain actors which would undertake studies to analyse the variables required.

In this regard, Eucobat would like to inform you that it stands ready to contribute to study the lifecycle and hoarding of batteries in several Member States, as already done with the previous Eucobat/Möbius 2017 study, and to possibly study other variables.

What is more, having specific provisions from the start in the Battery Regulation concerning the 'Available for Collection' methodology and the associated reporting from the concerned actors could guarantee Member States and the European Commission that data would be provided, thus ensuring that this new forward-looking legislation on batteries and its collection aspects contributes as best as possible to the objectives of the New Circular Economy Action Plan and of the Green Deal.

Therefore, as your presentation rightly highlighted, a combination of both Option 2 together with Option B definitely constitutes the way forward in order to provide a realistic and adapted methodology, fitting with the reality of the market and of the waste streams.

On the contrary, with Options A or C, we believe that adopting first a 'PAfC' methodology could hamper the production of data, given that there is no guarantee that actors concerned would be incentivised to produce data on waste flows and waste batteries not collectable, as only the lifespan of batteries would be considered.

This could very well lead to slowing down the adoption of an AfC methodology, if actors concerned are not incentivised and/or required to produce the necessary data. Moreover, given the evolution of the market, it could also lead to a situation where PROs and Member States do not achieve collection targets, as the PAfC methodology would not take into account all variables representing rightly the amount of waste batteries available for collection.

Eucobat would like to thank once again the Joint Research Centre and the European Commission for the extensive and very good work done with the Battery Regulation.
We were pleased to note that most, if not all, stakeholders consulted during the workshops have underlined the necessity to adopt an 'Available for Collection' methodology as soon as possible and to build on this basis. With the objective of collecting more waste batteries, Eucobat also hopes that collection targets will be realistic and achievable, reflecting the actual collection performance.
We are looking forward to hearing more about the conclusions of your report in June and are fully at your disposal should you wish to discuss certain points further.

EPBA

EPBA welcomes the opportunity to provide further comments to the Joint Research Center (JRC) in relation to the evaluation of the calculation methodology for portable batteries.
The assessment and options presented by JRC at the workshop on 19 May 2021 are important in relation to developing a policy framework which reflects the realities of the portable battery market. Although JRC approached the discussion from a technical point of view, it is important to evaluate as well the impact of these findings on the achievability of the collection targets as currently proposed by the European Commission.
We would like to make the following comments on the options presented during the workshop:
LMT products
We support option 2 in which LMT batteries have a definition separate from portable batteries.
A clear distinction needs to be made between these batteries for the following reasons:

- The lifespan of LMT batteries will in general be longer than the 'traditional' portable batteries. The lifespan of LMT batteries is also influenced by the reparability of these products which is not the case for the regular primary and rechargeable portable batteries.
- The market dynamics for LMT are different compared to portable batteries.
- The collection and end-of-life management is significantly different for LMT batteries. Dedicated and separate collection routes are needed for LMT due to their size and weight.
- The average weight of LMT batteries is significantly higher than regular portable batteries

We also want to underline that option 3 is not a suitable solution moving forward since it implies separate collection targets for both primary and rechargeable portable batteries.
This would be confusing for the consumer and will have a negative impact on the collection results. It is also a given that a clear-cut distinction between primary and rechargeable will anyhow not be made by all consumers when bringing their waste batteries to the collection points.
Methodology collection basis calculation
EPBA supports a calculation methodology based on what is 'availability for collection' since it reflects much better the realities of the battery market than the current methodology of POM while still allowing for ambitious collection targets.
The options listed by JRC give a good view on the various requirements which are to be taken into account to come to an efficient calculation methodology. We can understand the value of option C which foresees a two-phased implementation which allows for some time to undertake the necessary studies. It is however important that with this option clear and

ACEM

First I would like to state that ACEM appreciates the battery centric approach the JRC is proposing. Given the short notice it is hard for our members to provide further data on battery weight and capacity, however we would like to stress the following:

- The L3e category is very broad and a separation in the typical capacities and weight of batteries for each subcategory (table in slide 10) would give a better overview of the technology implemented.

- Battery capacity and weight are correlated, therefore we advise that you eliminate such redundancy by considering only one of the two factors when it comes to classification.
    - You are proposing (as an example) an upper weight limit of 20kg for defining LMT batteries which – I believe – is coming from the upper limit of battery weight for the L3e-A1 category. However, when considering light weight mopeds that can go up to 70 km/h, the typical battery weight range should be widened to at least 25+ kg considering the current market evolution (as an example the Vespa Elettrica has a battery of 25kg). Further the increase would reduce the gap to the 50kg lower end of bigger motorcycles batteries
- In our view it is very difficult to predict the battery technology beyond 2030. We therefore propose to include some sort of confidence interval to the prediction considering a slow or fast evolution of battery capacity over weight.
    - Regarding the battery weight evolution: as motorcycle designers we strive to keep the weight of our vehicles as low as possible and we therefore disagree with your prediction that the battery weight is going to increase with time for e-motorcycles (slide 47).
- We would also like to stress the fact that modifying definitions (e.g. portable batteries and light means of transport on slide 18) has an effect on other articles and requirements as well. This makes it difficult for ACEM to provide a stance on the LMT definition since the effect of such amendments on the whole battery regulation text is not fully clear at the moment.

EGMF

Given the very short time to provide feedbacks, EGMF would like to raise two general comments that are in line with my intervention toady:

- Possible consequences of creating a new category should be properly considered: solving the issue for light means of transport should not results in problems for other equipment in the portable category. Besides the collection target, the battery categories are also used in the proposed Regulation to apply requirements that differ from one category to another. The inclusion of a weight parameter already splits garden machinery and outdoor power equipment in two categories: portable and industrial batteries. Our equipment should not be further split in additional categories to maintain clarity for manufacturers as well as consumers, collectors and recyclers.
- In general, EGMF supports the effort made to improve the calculation of collection targets, notably taking into consideration the availability of waste batteries.

Annex 4: Batteries characteristics

Primary batteries

Table S 1: Capacity, Weight and lifetime values for primary batteries for different scenarios and years

Battery key	Parameter	Unit of measure	Scenario	2020	2030	2040
Alkaline	Capacity	[Wh/battery]	LDS	5.3	5.3	5.3
			MDS	5.3	5.7	6.1
			HDS	5.3	6.2	7.1
	Weight	[g/battery]	LDS	31.3	26.0	23.7
			MDS	31.3	30.3	29.3
			HDS	31.3	34.7	36.1
	Lifetime	[years]	LDS	4.9		
			MDS	4.0		
			HDS	3.7		

Li primary	Capacity	[Wh/battery]	LDS	1.8	1.8	1.8
			MDS	1.8	1.9	2.0
			HDS	1.8	2.1	2.4
	Weight	[g/battery]	LDS	7.4	6.2	5.6
			MDS	7.4	7.2	7.0
			HDS	7.4	8.3	8.6
	Lifetime	[years]	LDS	6.9		
			MDS	6.0		
			HDS	5.5		

Rechargeable batteries

Table S 2: Capacity, Weight and lifetime values for rechargeable batteries for different scenarios and years

Battery key	Parameter	Unit of measure	Scenario	2020	2030	2040
Portable PC	Capacity	[Wh/battery]	LDS	82.2	71.2	60.3
			MDS	82.2	87.6	93.1
			HDS	82.2	95.9	109.6
	Weight	[g/battery]	LDS	390.8	257.4	198.0
			MDS	390.8	342.8	331.1
			HDS	390.8	400.2	415.8
	Lifetime	[years]	LDS	7.1		
			MDS	6.2		
			HDS	5.7		
cell phones	Capacity	[Wh/battery]	LDS	9.7	8.9	8.1
			MDS	9.7	10.4	11.0
			HDS	9.7	11.0	12.3
	Weight	[g/battery]	LDS	30.0	18.1	15.0
			MDS	30.0	22.7	21.9
			HDS	30.0	26.4	26.8
	Lifetime	[years]	LDS	8.8		
			MDS	7.5		
			HDS	6.7		
Cameras games	Capacity	[Wh/battery]	LDS	58.8	53.9	49.0
			MDS	58.8	62.8	66.7
			HDS	58.8	66.7	74.5
	Weight	[g/battery]	LDS	170.6	115.1	95.1
			MDS	170.6	144.1	139.2
			HDS	170.6	164.8	167.5
	Lifetime	[years]	LDS	7.6		
			MDS	6.7		
			HDS	6.2		
tablets	Capacity	[Wh/battery]	LDS	65.0	59.6	54.2
			MDS	65.0	69.3	73.6
			HDS	65.0	73.6	82.3

	Weight	[g/battery]	LDS	184.1	116.3	96.1
			MDS	184.1	144.5	139.6
			HDS	184.1	167.9	170.6
	Lifetime	[years]	LDS	8.8		
			MDS	7.5		
			HDS	6.7		
Cordless tools	Capacity	[Wh/battery]	LDS	54.4	62.1	69.9
			MDS	54.4	64.2	74.0
			HDS	54.4	68.6	82.8
	Weight	[g/battery]	LDS	493.7	404.2	384.3
			MDS	493.7	465.7	463.7
			HDS	493.7	598.4	683.2
	Lifetime	[years]	LDS	11.8		
			MDS	10.3		
			HDS	9.3		
Other rechargeable	Capacity	[Wh/battery]	LDS	37.3	39.6	41.9
			MDS	37.3	41.6	45.9
			HDS	37.3	44.1	50.8
	Weight	[g/battery]	LDS	392.6	322.1	297.7
			MDS	392.6	373.6	364.9
			HDS	392.6	433.1	455.8
	Lifetime	[years]	LDS	9.1		
			MDS	7.9		
			HDS	7.2		

LMT batteries

Table S 3: Capacity, Weight and lifetime values for LMT batteries for different scenarios and years

Battery key	Parameter	Unit of measure	Scenario	2020	2030	2040
Small PLEVs batteries	Capacity	[kWh/battery]	LDS	0.4	0.5	0.6
			MDS	0.4	0.5	0.7
			HDS	0.4	0.6	0.9
	Weight	[kg/battery]	LDS	2.4	1.4	1.3
			MDS	2.4	1.8	1.8
			HDS	2.4	2.3	2.4
	Lifetime	[years]	LDS	4.0		
			MDS	3.0	2.7	3.4
			HDS	2.4		
E-scooters batteries	Capacity	[kWh/battery]	LDS	0.5	0.6	0.7
			MDS	0.5	0.6	0.8
			HDS	0.5	0.7	1.0
	Weight	[kg/battery]	LDS	2.7	1.7	1.5
			MDS	2.7	2.1	2.1
			HDS	2.7	2.7	2.8
	Lifetime	[years]	LDS	2.7		

			MDS	1.8	1.3	2.2
			HDS	1.5		
E-bikes batteries	Capacity	[kWh/battery]	LDS	0.5	0.6	0.8
			MDS	0.5	0.8	1.1
			HDS	0.5	0.9	1.3
	Weight	[kg/battery]	LDS	2.7	1.9	1.9
			MDS	2.7	2.5	2.6
			HDS	2.7	3.2	3.6
	Lifetime	[years]	LDS	11.3		
			MDS	10.0		
			HDS	8.6		
E-mopeds batteries	Capacity	[kWh/battery]	LDS	2.0	2.8	3.4
			MDS	2.0	2.9	3.6
			HDS	2.0	2.9	3.9
	Weight	[kg/battery]	LDS	12.1	8.4	7.8
			MDS	12.1	9.5	9.1
			HDS	12.1	10.9	10.7
	Lifetime	[years]	LDS	7.0		
			MDS	4.6		
			HDS	2.8		
E-motorcycles batteries	Capacity	[kWh/battery]	LDS	14.4	17.5	20.6
			MDS	14.4	17.7	21.2
			HDS	14.4	18.2	22.0
	Weight	[kg/battery]	LDS	62.7	38.2	33.7
			MDS	62.7	42.5	38.2
			HDS	62.7	48.6	44.0
	Lifetime	[years]	LDS	10.9		
			MDS	10.0		
			HDS	9.1		

Annex 5: Batteries flows

Portable primary batteries

Table S 4: CAGR for portable primary batteries

			CAGR 2020 - 2030	CAGR 2030 - 2040	CAGR 2040 - 2050
Primary	Alkaline	LDS	0.9%	0.5%	0.0%
		MDS	1.4%	1.0%	0.5%
		HDS	2.0%	1.0%	0.0%
	Li	LDS	2.5%	1.6%	1.0%
		MDS	3.7%	2.5%	1.6%
		HDS	4.3%	3.1%	2.2%
	Other	LDS	0.0%	0.0%	0.0%
		MDS	0.0%	0.0%	0.0%
		HDS	0.0%	0.0%	0.0%

Portable rechargeable batteries

Table S 5: CAGR for portable rechargeable batteries

			CAGR 2020 - 2030	CAGR 2030 - 2040	CAGR 2040 - 2050
Portable PC	NMC	LDS	3.7%	2.8%	2.2%
		MDS	3.7%	2.5%	1.6%
		HDS	4.9%	3.4%	2.2%
	LCO	LDS	2.5%	1.6%	1.0%
		MDS	2.5%	1.6%	1.0%
		HDS	3.7%	2.5%	1.6%
	NiMH	LDS	0.0%	0.0%	0.0%
		MDS	0.0%	0.0%	0.0%
		HDS	0.0%	0.0%	0.0%
Cell phones	NMC	LDS	4.9%	3.4%	2.2%
		MDS	12.8%	10.6%	7.9%
		HDS	4.9%	3.4%	2.2%
	LCO	LDS	1.4%	1.6%	1.0%
		MDS	-0.5%	-0.5%	-1.0%
		HDS	2.5%	2.5%	1.6%
Cameras / games	LCO	LDS	-2.5%	-3.7%	-4.6%
		MDS	-1.7%	-2.6%	-3.4%
		HDS	-1.0%	-1.4%	-1.8%
	NMC	LDS	2.0%	1.6%	1.0%
		MDS	3.0%	2.5%	1.6%
		HDS	2.0%	1.6%	1.0%
	LMO	LDS	-2.4%	-3.7%	-4.6%
		MDS	-1.7%	-2.6%	-3.4%
		HDS	0.0%	-1.0%	-1.8%
Tablets	LCO	LDS	-2.9%	-2.2%	-1.8%
		MDS	-2.2%	-1.4%	-1.0%
		HDS	-2.2%	-1.0%	0.0%
	NMC	LDS	0.5%	0.5%	0.0%
		MDS	1.4%	1.6%	1.0%
		HDS	2.5%	2.8%	2.2%
Cordless tools	NMC	LDS	3.0%	1.0%	0.0%
		MDS	5.0%	2.2%	1.0%

		HDS	5.5%	3.4%	2.2%
	NiCd	LDS	0.0%	0.0%	0.0%
		MDS	0.0%	0.0%	0.0%
		HDS	0.0%	0.0%	0.0%
	NiMH	LDS	0.0%	0.0%	0.0%
		MDS	-7.7%	-10.0%	0.0%
		HDS	-6.1%	-8.6%	-9.4%
Other portables	LMO	LDS	-7.6%	-9.3%	-9.7%
		MDS	-5.9%	-8.1%	-8.9%
		HDS	-3.4%	-5.4%	-6.5%
	NiMH	LDS	0.0%	0.0%	
		MDS	0.0%	0.0%	0.0%
		HDS	0.0%	0.0%	0.0%
	PbA	LDS	-8.7%	-9.4%	-9.7%
		MDS	-9.2%	-10.0%	0.0%
		HDS	-7.7%	-9.9%	-10.0%
	LFP	LDS	6.9%	5.5%	3.4%
		MDS	4.2%	3.4%	2.2%
		HDS	10.0%	7.9%	4.8%
	NMC	LDS	2.5%	1.0%	0.0%
		MDS	3.6%	2.2%	1.0%
		HDS	4.6%	3.4%	2.2%
	NiCd	LDS	0.0%	0.0%	0.0%
		MDS	0.0%	0.0%	0.0%
		HDS	0.0%	0.0%	0.0%

LMT batteries

Table S 6: CAGR for LMT batteries

		CAGR 2020 - 2030	CAGR 2030 - 2040	CAGR 2040 - 2050
Small PLEVs	LDS	6%	5%	3%
	MDS	10%	5%	3%
	HDS	14%	5%	3%
E-scooters	LDS	4%	3%	2%
	MDS	6%	3%	2%
	HDS	9%	3%	2%
E-bikes	LDS	8%	1%	1%
	MDS	12%	1%	1%
	HDS	17%	1%	1%
E-mopeds	LDS	52%	2%	1%
	MDS	67%	2%	1%
	HDS	82%	2%	1%
E-motorcycles	LDS	215%	5%	3%
	MDS	272%	5%	3%
	HDS	328%	5%	3%

Annex 6. Initial dataset

Placed on market

Table S 7: Number of primary batteries POM for the different scenarios

LDS	Alkaline [million units]	Li primary [million units]
2010	4,617	90
2020	4,422	441
2030	4,836	553
2040	5,083	642
2050	5,083	709

MDS	Alkaline [million units]	Li primary [million units]
2010	4,617	90
2020	4,422	441
2030	5,056	604
2040	5,584	754
2050	5,870	875

HDS	Alkaline [million units]	Li primary [million units]
2010	4,617	90
2020	4,422	441
2030	5,285	631
2040	5,835	827
2050	5,835	1,008

Table S 8: Tonnage of primary batteries POM for the different scenarios

LDS	Alkaline [ton]	Li primary [ton]
2010	144,267	667
2020	138,182	3,282
2030	125,940	3,432
2040	120,331	3,620
2050	110,304	3,666

MDS	Alkaline [ton]	Li primary [ton]
2010	144,267	667
2020	138,182	3,282
2030	153,209	4,360
2040	163,448	5,259
2050	166,754	5,924

HDS	Alkaline [ton]	Li primary [ton]
2010	144,267	667
2020	138,182	3,282
2030	183,490	5,218
2040	210,480	7,109
2050	217,058	8,937

Table S 9: Number of rechargeable batteries POM for the different scenarios

LDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	50	185	23	3	18	52
2020	46	171	25	44	67	148
2030	58	199	20	33	87	181
2040	69	234	14	27	96	202
2050	77	262	10	23	96	204

MDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	50	185	23	3	18	52
2020	46	171	25	44	67	148
2030	58	179	22	36	100	195
2040	68	201	18	32	122	237
2050	76	233	14	30	135	262

HDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	50	185	23	3	18	52
2020	46	171	25	44	67	148
2030	64	216	23	36	104	213
2040	80	271	21	35	140	286
2050	94	316	18	36	170	351

Table S 10: Tonnage of rechargeable batteries POM for the different scenarios

LDS	Portable PC [tons]	Cell phones [tons]	Cameras / Games [tons]	Tablets [tons]	Cordless tools [tons]	Other tons]
2010	15,173	4,974	3,973	431	7,895	11,167
2020	12,157	4,060	4,222	8,215	19,633	30,773
2030	10,259	3,386	2,384	4,326	19,411	24,097
2040	9,275	3,301	1,360	2,874	24,323	29,452
2050	7,792	3,046	725	1,994	26,741	32,470

MDS	Portable PC [tons]	Cell phones [tons]	Cameras / Games [tons]	Tablets [tons]	Cordless tools [tons]	Other tons]
2010	15,173	4,974	3,973	431	7,895	11,167
2020	12,157	4,060	4,222	8,215	19,633	30,773
2030	13,286	3,779	3,212	5,800	24,418	28,184
2040	15,040	4,213	2,473	4,992	33,775	38,274
2050	16,238	4,884	1,815	4,514	41,040	46,470

HDS	Portable PC [tons]	Cell phones [tons]	Cameras / Games [tons]	Tablets [tons]	Cordless tools [tons]	Other tons]
2010	15,173	4,974	3,973	431	7,895	11,167
2020	12,157	4,060	4,222	8,215	19,633	30,773
2030	17,212	5,161	4,003	6,747	24,656	31,166
2040	22,558	6,600	3,642	6,495	34,353	41,652
2050	27,191	7,804	3,155	6,805	43,177	52,795

Table S 11: Number of LMT batteries POM for the different scenarios

LDS	Small PLEVs [million units]	E-scooters [million units]	E-bikes [million units]	E-mopeds [million units]	E-motorcycles [million units]
2010	0.0	0.0	0.6	0.0	0.0
2020	0.2	1.9	4.5	0.1	0.0
2030	0.3	2.7	8.0	0.4	0.4
2040	0.5	3.6	8.8	0.4	0.7
2050	0.7	4.4	9.6	0.5	0.9

MDS	Small PLEVs [million units]	E-scooters [million units]	E-bikes [million units]	E-mopeds [million units]	E-motorcycles [million units]
2010	0.0	0.0	0.6	0.0	0.0
2020	0.2	1.9	4.5	0.1	0.0
2030	0.4	3.0	10.0	0.5	0.6
2040	0.6	4.0	11.0	0.5	0.8
2050	0.9	4.9	12.0	0.6	1.1

HDS	Small PLEVs [million units]	E-scooters [million units]	E-bikes [million units]	E-mopeds [million units]	E-motorcycles [million units]
2010	0.0	0.0	0.6	0.0	0.0
2020	0.2	1.9	4.5	0.1	0.0
2030	0.5	3.6	12.0	0.5	0.7

2040	0.8	4.8	13.1	0.6	1.0
2050	1.0	5.8	14.4	0.7	1.4

Table S 12: Tonnage of LMT batteries POM for the different scenarios

LDS	Small PLEVs [tons]	E-scooters [tons]	E-bikes [tons]	E-mopeds [tons]	E-motorcycles [tons]
2010	57	24	1,601	89	52
2020	520	5,226	12,249	708	1,225
2030	498	4,522	15,418	3,020	16,815
2040	651	5,362	16,370	3,279	22,611
2050	792	6,028	17,590	3,580	27,960

MDS	Small PLEVs [tons]	E-scooters [tons]	E-bikes [tons]	E-mopeds [tons]	E-motorcycles [tons]
2010	57	24	1,601	89	52
2020	520	5,226	12,249	708	1,225
2030	782	6,429	25,017	4,291	23,358
2040	1,133	8,343	28,780	4,765	32,010
2050	1,480	9,970	32,429	5,280	40,131

HDS	Small PLEVs [tons]	E-scooters [tons]	E-bikes [tons]	E-mopeds [tons]	E-motorcycles [tons]
2010	57	24	1,601	89	52
2020	520	5,226	12,249	708	1,225
2030	1,203	9,749	38,444	5,867	32,048
2040	1,846	13,498	46,734	6,767	44,242
2050	2,495	16,764	54,228	7,680	55,756

Stocks

Table S 13: Stock of primary batteries for the different scenarios (in units)

LDS	Alkaline [million units]	Li primary [million units]	MDS	Alkaline [million units]	Li primary [million units]	HDS	Alkaline [million units]	Li primary [million units]
2010	18,667	244		14,684	235		13,016	227
2020	18,813	2,018		14,413	1,844		12,587	1,726
2030	19,655	3,261		15,639	3,019		14,212	2,839
2040	20,910	3,911		17,350	3,913		15,959	3,844
2050	20,690	4,346		17,891	4,562		15,424	4,695

Table S 14: Stock of primary batteries for the different scenarios (tonnage)

LDS	Alkaline [ton]	Li primary [ton]	MDS	Alkaline [ton]	Li primary [ton]	HDS	Alkaline [ton]	Li primary [ton]
2010	583,334	1,819		458,861	1,748		406,756	1,692
2020	587,900	15,022		450,396	13,730		393,332	12,847
2030	533,670	21,523		475,861	21,991		488,976	22,883
2040	501,003	22,842		508,717	27,561		579,826	32,730
2050	449,423	23,176		506,687	31,146		581,732	41,312

Table S 15: Stock of rechargeable batteries for the different scenarios (in units)

LDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	230	1,116	72	3	110	161
2020	305	1,302	179	319	415	1,027
2030	379	1,329	154	305	892	1,447
2040	460	1,607	117	242	1,199	1,696
2050	519	1,812	78	203	1,303	1,766

MDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	215	1,017	70	3	104	155
2020	265	1,138	157	285	393	949
2030	335	1,087	141	265	889	1,290
2040	404	1,240	120	233	1,266	1,650
2050	452	1,419	93	217	1,482	1,862

HDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	204	950	68	3	99	151
2020	241	1,040	144	261	375	889
2030	327	1,132	135	237	836	1,227
2040	429	1,476	125	216	1,256	1,731
2050	504	1,729	108	223	1,597	2,150

Table S 16: Stock of rechargeable batteries for the different scenarios (tonnage)

LDS	Portable PC [tons]	Cell phones [tons]	Cameras / Games [tons]	Tablets [tons]	Cordless tools [tons]	Other rechargeable [tons]
2010	73,373	30,024	12,292	430	51,900	41,850
2020	85,885	32,726	30,454	53,255	134,942	201,705
2030	77,095	25,727	21,289	47,094	230,021	227,218
2040	68,737	24,425	12,493	28,966	290,925	239,853
2050	58,705	22,772	6,607	19,728	336,387	269,581

MDS	Portable PC [tons]	Cell phones [tons]	Cameras / Games [tons]	Tablets [tons]	Cordless tools [tons]	Other rechargeable [tons]
2010	68,034	27,363	11,937	429	48,897	38,741
2020	74,021	28,427	26,818	48,112	125,912	184,585
2030	79,647	23,937	21,847	45,192	237,153	207,695
2040	89,910	26,128	17,110	36,560	333,102	255,932
2050	97,302	29,888	12,445	32,685	424,288	317,822

HDS	Portable PC [tons]	Cell phones [tons]	Cameras / Games [tons]	Tablets [tons]	Cordless tools [tons]	Other rechargeable [tons]

2010	64,297	25,556	11,666	428	46,294	36,644
2020	66,986	25,849	24,539	44,408	118,984	172,212
2030	87,966	27,128	23,079	44,121	218,352	199,461
2040	119,325	35,843	21,531	40,206	307,403	251,139
2050	144,654	42,638	18,670	41,708	398,561	318,789

Table S 17: Stock of LMT batteries for the different scenarios (in units)

LDS	**Small PLEVs [million units]**	**E-scooters [million units]**	**E-bikes [million units]**	**E-mopeds [million units]**	**E-motorcycles [million units]**
2010	0.1	0.0	1.5	0.0	0.0
2020	0.4	2.6	17.4	0.2	0.1
2030	1.1	5.3	58.2	1.5	2.2
2040	1.6	6.7	84.8	2.5	5.4
2050	2.1	7.7	96.9	2.9	7.9

MDS	**Small PLEVs [million units]**	**E-scooters [million units]**	**E-bikes [million units]**	**E-mopeds [million units]**	**E-motorcycles [million units]**
2010	0.0	0.0	1.5	0.0	0.0
2020	0.4	1.8	16.8	0.1	0.1
2030	0.8	1.4	68.0	1.4	2.7
2040	1.5	3.8	95.4	2.0	6.4
2050	2.3	8.3	106.8	2.3	9.2

HDS	**Small PLEVs [million units]**	**E-scooters [million units]**	**E-bikes [million units]**	**E-mopeds [million units]**	**E-motorcycles [million units]**
2010	0.0	0.0	1.4	0.0	0.0
2020	0.3	1.5	15.9	0.1	0.1
2030	0.8	2.4	66.9	1.0	3.1
2040	1.1	2.1	99.3	1.3	7.1
2050	1.4	1.2	111.2	1.4	10.2

Table S 18: Stock of LMT batteries for the different scenarios (tonnage)

LDS	**Small PLEVs [tons]**	**E-scooters [tons]**	**E-bikes [tons]**	**E-mopeds [tons]**	**E-motorcycles [tons]**
2010	149	43	4,032	346	256
2020	1,061	7,097	47,399	2,177	3,328
2030	1,659	9,129	127,612	13,992	96,042
2040	2,022	9,769	164,340	20,026	193,958
2050	2,447	10,303	180,200	22,066	256,826

MDS	**Small PLEVs [tons]**	**E-scooters [tons]**	**E-bikes [tons]**	**E-mopeds [tons]**	**E-motorcycles [tons]**
2010	115	25	3,981	267	251
2020	861	4,983	45,609	1,766	3,271
2030	1,545	2,825	174,727	13,905	125,228
2040	2,554	7,712	246,188	18,313	254,817
2050	3,923	16,547	284,172	20,045	339,038

HDS	Small PLEVs [tons]	E-scooters [tons]	E-bikes [tons]	E-mopeds [tons]	E-motorcycles [tons]
2010	87	18	3,908	168	244
2020	692	4,072	43,311	1,230	3,205
2030	1,852	6,551	205,593	11,239	161,391
2040	2,728	6,079	338,276	13,500	325,753
2050	3,468	3,772	407,760	14,434	431,518

Potentially available for collection

Table S 19: Number of waste primary batteries for the different scenarios

LDS	Alkaline [million units]	Li primary [million units]
2010	4,259	17
2020	4,514	228
2030	4,670	477
2040	5,064	591
2050	5,114	667

MDS	Alkaline [million units]	Li primary [million units]
2010	4,344	21
2020	4,515	255
2030	4,848	512
2040	5,508	683
2050	5,818	809

HDS	Alkaline [million units]	Li primary [million units]
2010	4,381	24
2020	4,515	272
2030	5,024	534
2040	5,852	741
2050	5,893	918

Table S 20: Tonnage of waste primary batteries for the different scenarios

LDS	Alkaline [ton]	Li primary [ton]
2010	133,081	127
2020	141,051	1,696
2030	131,128	3,274
2040	125,055	3,548
2050	115,296	3,640

MDS	Alkaline [ton]	Li primary [ton]
2010	135,754	156
2020	141,103	1,897
2030	148,391	3,752
2040	163,091	4,846
2050	166,959	5,562

HDS	Alkaline [ton]	Li primary [ton]
2010	136,903	178
2020	141,107	2,027
2030	169,285	4,216
2040	208,765	6,258
2050	217,233	8,018

Table S 21: Number of waste rechargeable batteries for the different scenarios

LDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	19	115	3	0	6	4
2020	44	180	24	27	18	66
2030	50	176	23	40	47	158
2040	62	210	18	32	76	185
2050	71	241	13	26	92	201

MDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	22	130	4	0	7	6
2020	44	182	25	33	20	81
2030	51	169	24	40	55	164
2040	63	187	21	35	93	209
2050	71	208	16	32	117	243

HDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	24	139	4	0	8	7
2020	44	183	25	37	22	92
2030	54	184	24	40	60	170
2040	72	243	23	35	102	242
2050	86	290	20	35	137	308

Table S 22: Tonnage of waste rechargeable batteries for the different scenarios

LDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	6,438	3,108	522	1	3,082	2,558
2020	13,117	4,707	4,085	4,160	6,917	14,860
2030	11,491	3,781	3,566	6,642	13,274	27,311
2040	10,122	3,414	2,119	4,145	18,904	26,360
2050	8,842	3,226	1,154	2,733	22,787	29,749

MDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	7,485	3,507	658	2	3,633	2,896
2020	12,962	4,715	4,269	5,234	7,581	17,427
2030	12,648	3,849	3,805	7,020	15,791	28,621
2040	14,156	3,939	2,987	5,526	24,250	31,876
2050	15,496	4,354	2,200	4,845	32,130	40,345

HDS	Portable PC [million units]	Cell phones [million units]	Cameras / Games [million units]	Tablets [million units]	Cordless tools [million units]	Other rechargeable [million units]
2010	8,138	3,736	764	3	4,075	3,152
2020	12,753	4,710	4,337	5,884	8,067	19,273
2030	14,322	4,388	4,122	7,359	16,867	30,002
2040	19,898	5,872	3,906	6,519	25,293	35,478
2050	24,539	7,096	3,424	6,611	33,784	45,377

Table S 23: Number of waste LMT batteries for the different scenarios

LDS	Small PLEVs [million units]	E-scooters [million units]	E-bikes [million units]	E-mopeds [million units]	E-motorcycles [million units]
2010	0.02	0.01	0.04	0.00	0.00
2020	0.10	0.94	0.81	0.02	0.00
2030	0.30	2.57	3.89	0.18	0.09
2040	0.46	3.46	7.06	0.37	0.39
2050	0.63	4.28	8.61	0.44	0.66

MDS	Small PLEVs [million units]	E-scooters [million units]	E-bikes [million units]	E-mopeds [million units]	E-motorcycles [million units]
2010	0.02	0.01	0.05	0.00	0.00
2020	0.12	1.29	0.95	0.03	0.00

2030	0.40	3.20	5.30	0.30	0.13
2040	0.56	3.63	9.35	0.50	0.53
2050	0.78	4.35	10.97	0.57	0.85

HDS	Small PLEVs [million units]	E-scooters [million units]	E-bikes [million units]	E-mopeds [million units]	E-motorcycles [million units]
2010	0.02	0.01	0.06	0.01	0.00
2020	0.14	1.44	1.12	0.04	0.00
2030	0.47	3.56	6.14	0.44	0.18
2040	0.74	4.86	11.43	0.62	0.67
2050	1.01	5.94	13.38	0.71	1.05

Table S 24: Tonnage of waste LMT batteries for the different scenarios

LDS	Small PLEVs [tons]	E-scooters [tons]	E-bikes [tons]	E-mopeds [tons]	E-motorcycles [tons]
2010	38	19	109	38	10
2020	245	2,548	2,199	212	96
2030	496	4,657	9,148	1,737	4,378
2040	606	5,269	14,189	2,999	15,009
2050	751	5,984	16,231	3,393	22,264

MDS	Small PLEVs [tons]	E-scooters [tons]	E-bikes [tons]	E-mopeds [tons]	E-motorcycles [tons]
2010	44	21	135	54	12
2020	299	3,521	2,581	311	109
2030	755	6,962	13,828	3,016	6,497
2040	993	7,595	23,968	4,581	22,071
2050	1,344	8,957	28,872	5,105	32,322

HDS	Small PLEVs [tons]	E-scooters [tons]	E-bikes [tons]	E-mopeds [tons]	E-motorcycles [tons]
2010	48	22	171	70	14
2020	347	3,909	3,058	462	124
2030	1,102	9,643	18,340	4,841	9,717
2040	1,765	13,613	37,874	6,667	31,975
2050	2,427	17,054	48,103	7,592	45,794

Annex 7. Sensitivity analysis

Correspondence levels varying the lifespan

Figure S 1: Rechargeable batteries in case of Option 1 – lower lifespan compared to the MDS lifespan

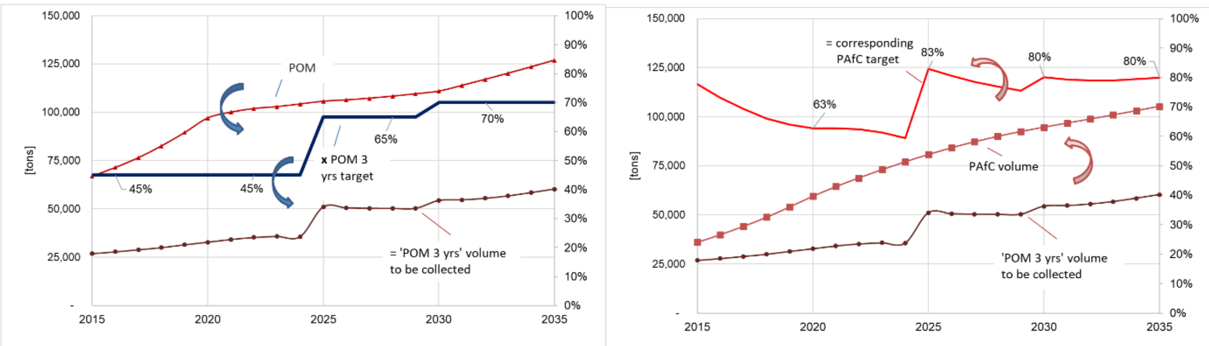


Figure S 2: Rechargeable batteries in case of Option 1 – higher lifespan compared to the MDS lifespan

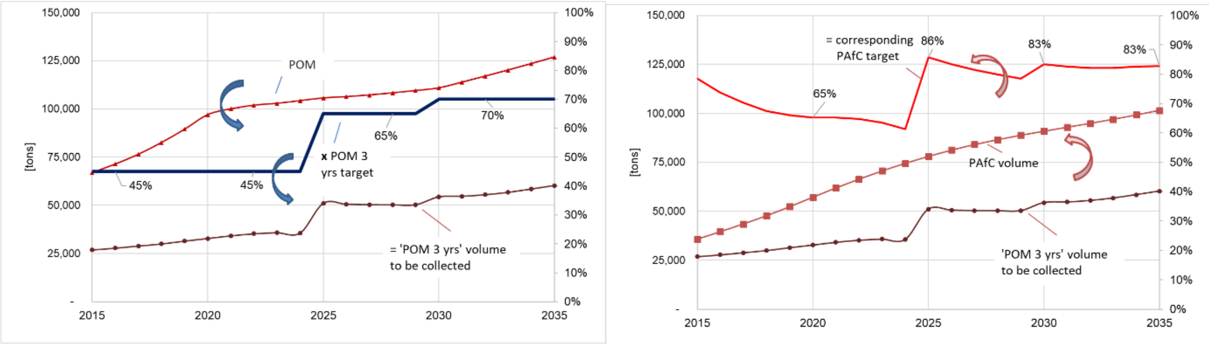


Figure S 3: LMT batteries in case of Option 2/3 (excluding e-motorcycles batteries) – lower lifespan compared to the MDS lifespan

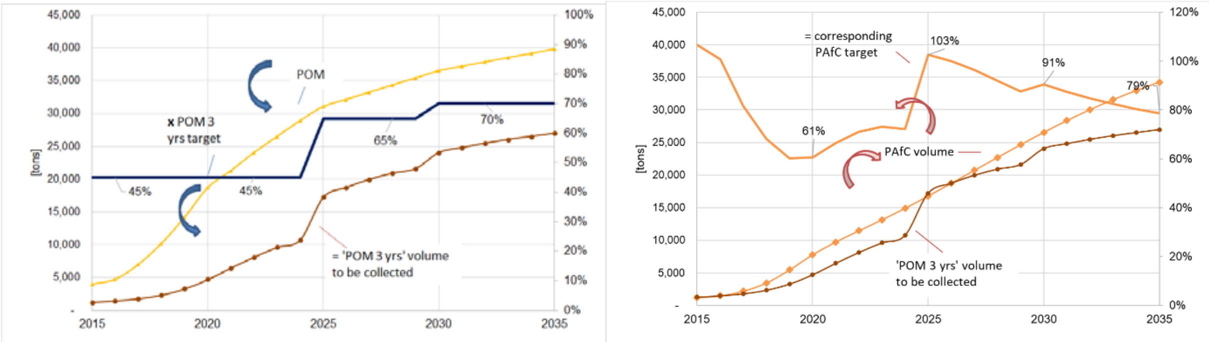


Figure S 4: LMT batteries in case of Option 2/3 (excluding e-motorcycles batteries) – higher lifespan compared to the MDS lifespan

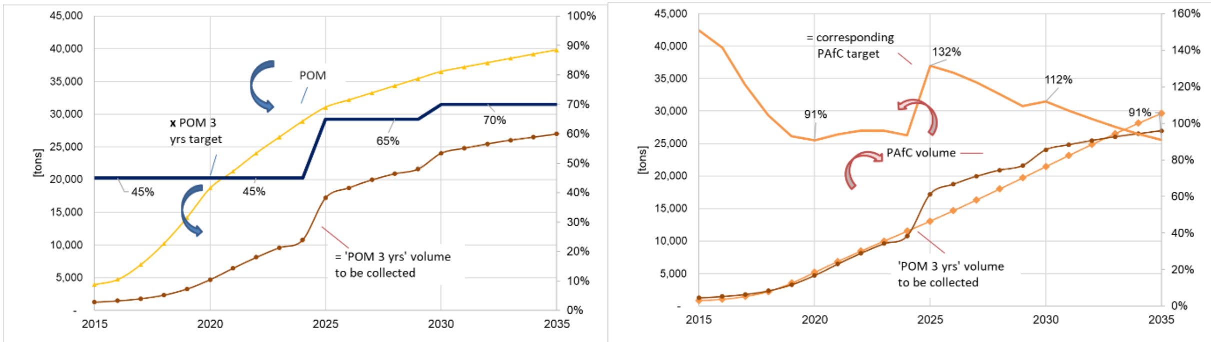


Figure S 5: LMT batteries in case of Option 2/3 (including e-motorcycles batteries) – lower lifespan compared to the MDS lifespan

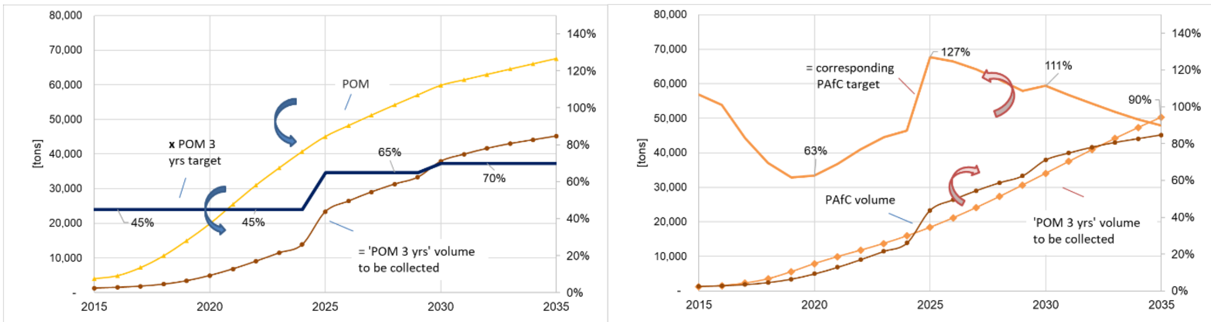
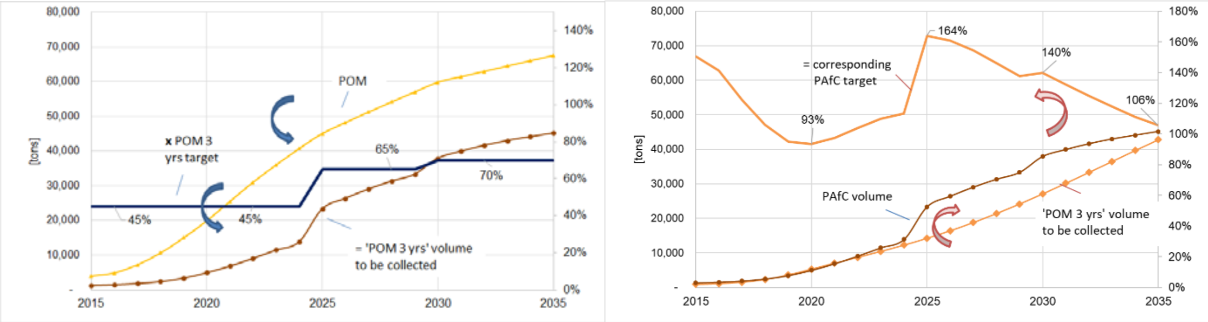


Figure S 6: LMT batteries in case of Option 2/3 (including e-motorcycles batteries) – higher lifespan compared to the MDS lifespan



Correspondence levels varying the energy density

Figure S 7: Rechargeable batteries in case of Option 1 – lower energy density compared to the MDS energy density

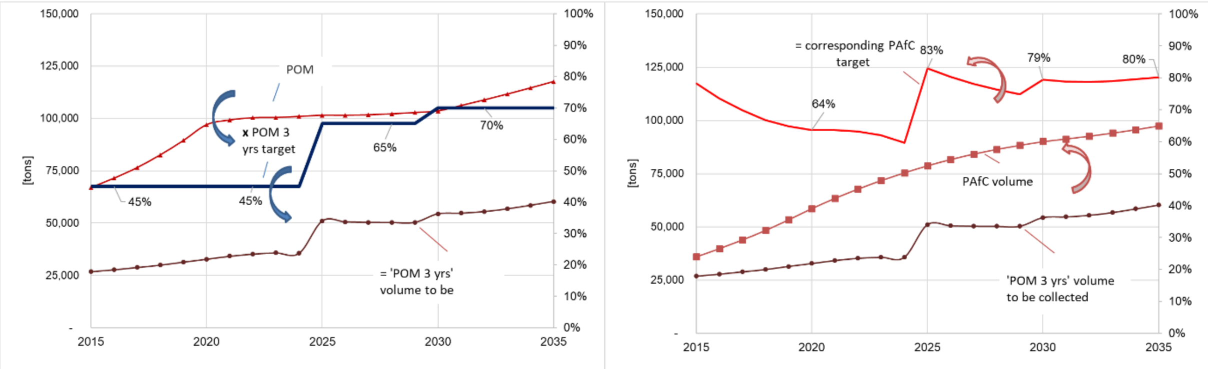


Figure S 8: Rechargeable batteries in case of Option 1 – higher energy density compared to the MDS energy density

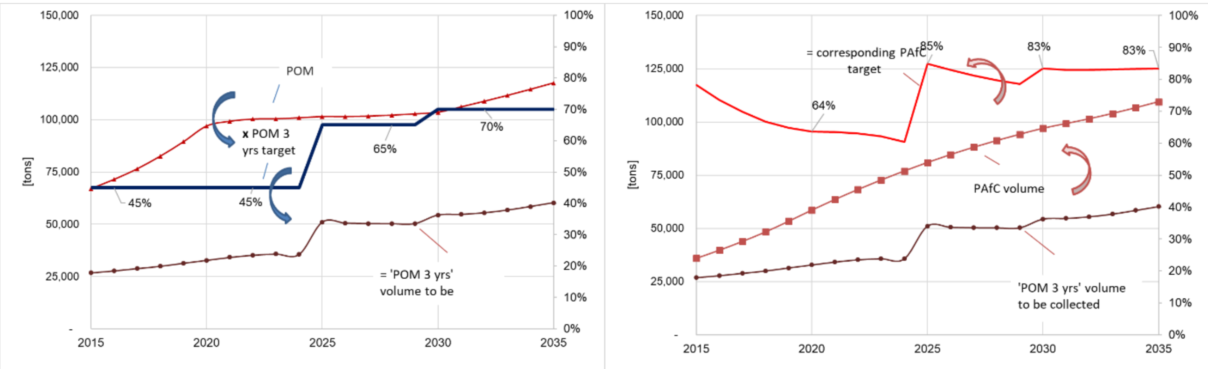


Figure S 9: LMT batteries in case of Option 2/3 (excluding e-motorcycles batteries) – lower energy density compared to the MDS energy density

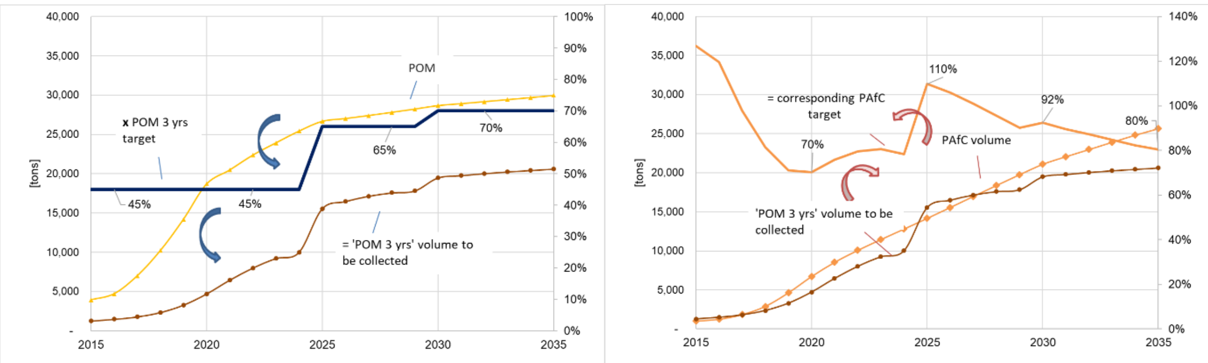


Figure S 10: LMT batteries in case of Option 2/3 (excluding e-motorcycles batteries) – higher energy density compared to the MDS energy density

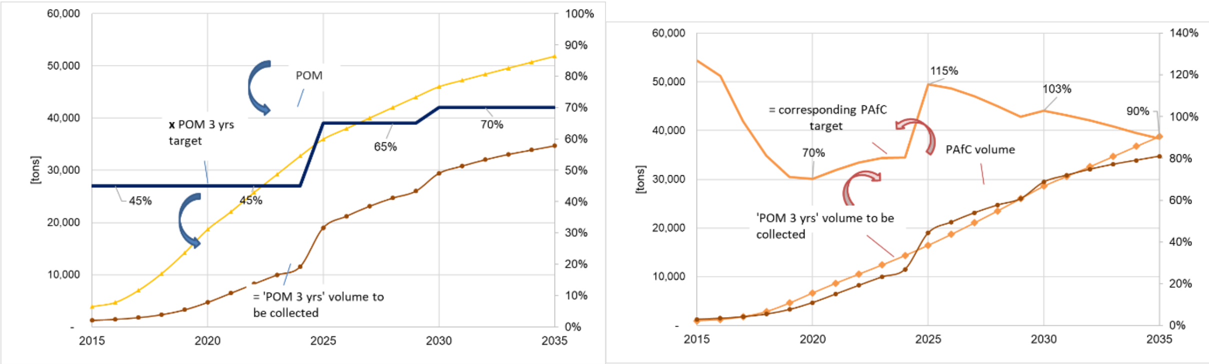


Figure S 11: LMT batteries in case of Option 2/3 (including e-motorcycles batteries) – lower energy density compared to the MDS energy density

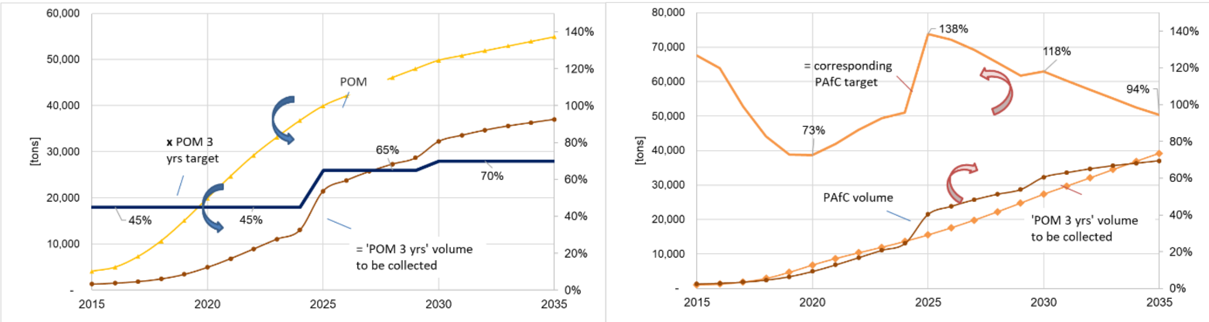
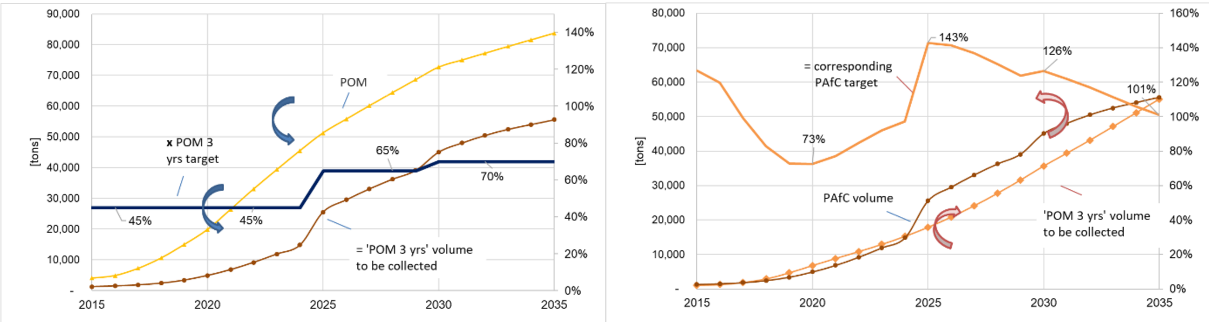


Figure S 12: LMT batteries in case of Option 2/3 (including e-motorcycles batteries) – higher energy density compared to the MDS energy density



Annex 8. Correspondence between the 'old' POM_{3yr} and the 'new' AfC target

Table S 25: POM data for the **MDS** scenario for LMT, Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	POM [tons]				POM target [%]	$POM_{3\ years}$ volume to be collected			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	3,946	63,188	148,576	215,710	45%	1,271	26,836	63,863	91,970
2016	4,723	66,883	143,471	215,076	45%	1,485	27,787	64,229	93,502
2017	7,004	69,867	141,017	217,888	45%	1,797	28,893	64,777	95,467
2018	10,220	72,899	141,159	224,278	45%	2,351	29,991	64,960	97,301
2019	14,206	75,964	141,308	231,478	45%	3,292	31,447	63,847	98,586
2020	18,703	79,060	141,464	239,227	45%	4,715	32,809	63,523	101,047
2021	21,287	79,941	141,161	242,389	45%	6,469	34,188	63,590	104,247
2022	24,052	79,484	142,864	246,400	45%	8,129	35,245	63,590	106,964
2023	26,508	78,389	144,597	249,494	45%	9,606	35,773	63,823	109,202
2024	28,930	77,704	146,359	252,993	45%	10,777	35,672	64,293	110,743
2025	31,068	77,343	148,150	256,561	65%	17,223	51,042	93,994	162,259
2026	32,162	77,244	149,972	259,379	65%	18,743	50,578	95,140	164,460
2027	33,254	77,360	151,824	262,439	65%	19,968	50,330	96,304	166,602
2028	34,344	77,655	153,708	265,707	65%	20,905	50,255	97,489	168,649
2029	35,432	78,102	155,622	269,156	65%	21,615	50,323	98,693	170,630
2030	36,519	78,679	157,568	272,766	70%	24,040	54,394	107,603	186,037
2031	37,193	81,019	159,403	277,614	70%	24,802	54,702	108,943	188,447

2032	37,860	83,483	161,270	282,612	70%	25,467	55,486	110,272	191,225
2033	38,521	86,067	163,169	287,757	70%	26,033	56,742	111,590	194,365
2034	39,177	88,768	165,101	293,046	70%	26,501	58,466	112,896	197,863
2035	39,828	91,587	167,066	298,480	70%	26,964	60,274	114,226	201,464
2036	40,474	92,894	167,375	300,743	70%	27,423	62,165	115,578	205,166
2037	41,117	94,330	167,693	303,140	70%	27,879	63,758	116,560	208,196
2038	41,755	95,788	168,022	305,565	70%	28,331	65,056	117,164	210,551
2039	42,390	97,267	168,360	308,017	70%	28,781	66,036	117,388	212,204
2040	43,022	98,767	168,707	310,496	70%	29,228	67,057	117,617	213,902
SUM	**For the years (2023 – 2035)**					**272,644**	**664,037**	**1,275,266**	**2,211,946**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 26: AfC data for the **MDS** scenario for LMT, Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	**Waste [tons]**				**POM target [%]**	**AfC volume to be collected (tons)**			
	LMT	**Rechargeable**	**Primary**	**TOTAL**		**LMT**	**Rechargeable**	**Primary**	**TOTAL**
2015	1,002	34,984	143,227	179,214	50.3%	504	17,588	72,005	90,097
2016	1,242	38,606	143,842	183,689	50.3%	625	19,408	72,314	92,347
2017	1,837	42,165	143,917	187,919	50.3%	924	21,198	72,352	94,473
2018	2,890	45,625	143,674	192,189	50.3%	1,453	22,937	72,230	96,620
2019	4,632	48,962	143,327	196,922	50.3%	2,329	24,615	72,056	98,999
2020	6,711	52,188	142,999	201,899	50.3%	3,374	26,237	71,891	101,501
2021	8,620	55,318	142,709	206,647	50.3%	4,333	27,810	71,745	103,889
2022	10,326	58,325	142,637	211,288	50.3%	5,191	29,322	71,709	106,222
2023	11,942	61,139	142,901	215,982	50.3%	6,004	30,737	71,841	108,582
2024	13,575	63,683	143,519	220,776	50.3%	6,824	32,015	72,152	110,992
2025	15,281	65,887	144,461	225,630	70.3%	10,739	46,301	101,518	158,558
2026	17,069	67,713	145,672	230,454	70.3%	11,995	47,584	102,369	161,948
2027	18,916	69,158	147,094	235,168	70.3%	13,293	48,599	103,368	165,260
2028	20,798	70,259	148,673	239,729	70.3%	14,615	49,373	104,477	168,466
2029	22,687	71,088	150,366	244,141	70.3%	15,943	49,956	105,667	171,566
2030	24,561	71,734	152,143	248,438	75.3%	18,488	53,997	114,524	187,008
2031	26,006	72,300	153,971	252,276	75.3%	19,576	54,422	115,899	189,897
2032	27,393	72,890	155,826	256,109	75.3%	20,620	54,867	117,295	192,782
2033	28,832	73,583	157,698	260,114	75.3%	21,703	55,389	118,705	195,796
2034	30,261	74,431	159,585	264,277	75.3%	22,778	56,027	120,125	198,930
2035	31,622	75,458	161,488	268,568	75.3%	23,803	56,800	121,558	202,161
2036	32,893	76,666	163,259	272,818	75.3%	24,760	57,709	122,891	205,360
2037	34,073	78,028	164,796	276,897	75.3%	25,648	58,734	124,047	208,430
2038	35,168	79,515	166,072	280,755	75.3%	26,472	59,853	125,008	211,334
2039	36,186	81,094	167,106	284,386	75.3%	27,239	61,042	125,787	214,067
2040	37,136	82,734	167,937	287,808	75.3%	27,954	62,277	126,412	216,643
SUM	(for the years 2023 - 2035)				**5.3%**	**206,380**	**636,068**	**1,369,498**	**2,211,946**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 27: POM data for the **LDS** scenario for LMT; **MDS** scenario for Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	POM [tons]				POM target [%]	POM$_{3\ years}$ volume to be collected			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	3,946	63,188	148,576	215,710	45%	1,271	26,836	63,863	91,970
2016	4,723	66,883	143,471	215,076	45%	1,485	27,787	64,229	93,502
2017	7,004	69,867	141,017	217,888	45%	1,797	28,893	64,777	95,467
2018	10,220	72,899	141,159	224,278	45%	2,351	29,991	64,960	97,301
2019	14,206	75,964	141,308	231,478	45%	3,292	31,447	63,847	98,586
2020	18,703	79,060	141,464	239,227	45%	4,715	32,809	63,523	101,047
2021	19,129	79,941	141,161	240,231	45%	6,469	34,188	63,590	104,247
2022	19,549	79,484	142,864	241,898	45%	7,806	35,245	63,590	106,640
2023	19,993	78,389	144,597	242,979	45%	8,607	35,773	63,823	108,203
2024	20,455	77,704	146,359	244,517	45%	8,801	35,672	64,293	108,766
2025	20,932	77,343	148,150	246,425	65%	12,999	51,042	93,994	158,036
2026	21,420	77,244	149,972	248,637	65%	13,299	50,578	95,140	159,016
2027	21,919	77,360	151,824	251,103	65%	13,608	50,330	96,304	160,242
2028	22,425	77,655	153,708	253,788	65%	13,925	50,255	97,489	161,669
2029	22,938	78,102	155,622	256,662	65%	14,249	50,323	98,693	163,264
2030	23,458	78,679	157,568	259,705	70%	15,699	54,394	107,603	177,696
2031	23,666	81,019	159,403	264,088	70%	16,058	54,702	108,943	179,703
2032	23,878	83,483	161,270	268,631	70%	16,348	55,486	110,272	182,106
2033	24,093	86,067	163,169	273,329	70%	16,567	56,742	111,590	184,899
2034	24,310	88,768	165,101	278,180	70%	16,715	58,466	112,896	188,078
2035	24,531	91,587	167,066	283,183	70%	16,866	60,274	114,226	191,366
2036	24,753	92,894	167,375	285,021	70%	17,018	62,165	115,578	194,761
2037	24,977	94,330	167,693	287,001	70%	17,172	63,758	116,560	197,490
2038	25,204	95,788	168,022	289,014	70%	17,328	65,056	117,164	199,548
2039	25,432	97,267	168,360	291,059	70%	17,485	66,036	117,388	200,908
2040	25,662	98,767	168,707	293,136	70%	17,643	67,057	117,617	202,317
SUM	**For the years (2023 – 2035)**					**183,742**	**664,037**	**1,275,266**	**2,123,044**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 28: AfC data for the **LDS** scenario for LMT; **MDS** scenario for Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	Waste [tons]				POM target [%]	AfC volume to be collected (tons)			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	843	34,984	143,227	179,055	49.6%	418	17,345	71,012	88,775
2016	1,051	38,606	143,842	183,498	49.6%	521	19,141	71,316	90,978
2017	1,485	42,165	143,917	187,566	49.6%	736	20,905	71,353	92,995
2018	2,253	45,625	143,674	191,552	49.6%	1,117	22,621	71,233	94,971
2019	3,542	48,962	143,327	195,831	49.6%	1,756	24,275	71,061	97,093
2020	5,204	52,188	142,999	200,392	49.6%	2,580	25,875	70,899	99,354
2021	6,797	55,318	142,709	204,825	49.6%	3,370	27,427	70,755	101,551
2022	8,191	58,325	142,637	209,153	49.6%	4,061	28,917	70,719	103,697
2023	9,400	61,139	142,901	213,440	49.6%	4,660	30,313	70,850	105,823
2024	10,476	63,683	143,519	217,678	49.6%	5,194	31,574	71,156	107,924
2025	11,472	65,887	144,461	221,820	69.6%	7,982	45,844	100,516	154,342
2026	12,422	67,713	145,672	225,808	69.6%	8,643	47,115	101,358	157,116
2027	13,348	69,158	147,094	229,600	69.6%	9,288	48,120	102,347	159,755
2028	14,259	70,259	148,673	233,191	69.6%	9,922	48,886	103,446	162,254
2029	15,157	71,088	150,366	236,611	69.6%	10,546	49,463	104,624	164,633
2030	16,038	71,734	152,143	239,915	74.6%	11,961	53,499	113,468	178,928
2031	16,913	72,300	153,971	243,183	74.6%	12,613	53,921	114,831	181,365
2032	17,771	72,890	155,826	246,486	74.6%	13,253	54,361	116,214	183,829
2033	18,600	73,583	157,698	249,881	74.6%	13,872	54,878	117,611	186,361
2034	19,388	74,431	159,585	253,404	74.6%	14,459	55,510	119,018	188,988
2035	20,128	75,458	161,488	257,075	74.6%	15,011	56,277	120,437	191,726
2036	20,816	76,666	163,259	260,742	74.6%	15,525	57,177	121,758	194,460
2037	21,452	78,028	164,796	264,276	74.6%	15,999	58,193	122,904	197,096
2038	22,036	79,515	166,072	267,623	74.6%	16,435	59,302	123,856	199,593
2039	22,572	81,094	167,106	270,773	74.6%	16,834	60,480	124,627	201,941
2040	23,064	82,734	167,937	273,736	74.6%	17,201	61,703	125,247	204,151
SUM	(for the years 2023 - 2035)				**4.6%**	**137,406**	**629,760**	**1,355,877**	**2,123,043**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 29: POM data for the **HDS** scenario for LMT; **MDS** scenario for Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	POM [tons]				POM target [%]	$POM_{3\ years}$ volume to be collected			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	3,946	63,188	148,576	215,710	45%	1,271	26,836	63,863	91,970
2016	4,723	66,883	143,471	215,076	45%	1,485	27,787	64,229	93,502
2017	7,004	69,867	141,017	217,888	45%	1,797	28,893	64,777	95,467
2018	10,220	72,899	141,159	224,278	45%	2,351	29,991	64,960	97,301
2019	14,206	75,964	141,308	231,478	45%	3,292	31,447	63,847	98,586
2020	18,703	79,060	141,464	239,227	45%	4,715	32,809	63,523	101,047
2021	22,217	79,941	141,161	243,319	45%	6,469	34,188	63,590	104,247
2022	25,777	79,484	142,864	248,126	45%	8,269	35,245	63,590	107,104
2023	29,376	78,389	144,597	252,362	45%	10,005	35,773	63,823	109,601
2024	33,007	77,704	146,359	257,069	45%	11,606	35,672	64,293	111,571
2025	36,665	77,343	148,150	262,159	65%	19,101	51,042	93,994	164,137
2026	40,348	77,244	149,972	267,564	65%	21,460	50,578	95,140	167,178
2027	44,051	77,360	151,824	273,236	65%	23,838	50,330	96,304	170,472
2028	47,773	77,655	153,708	279,136	65%	26,231	50,255	97,489	173,975
2029	51,511	78,102	155,622	285,234	65%	28,637	50,323	98,693	177,653
2030	55,263	78,679	157,568	291,510	70%	33,445	54,394	107,603	195,442
2031	56,707	81,019	159,403	297,129	70%	36,061	54,702	108,943	199,705
2032	58,127	83,483	161,270	302,880	70%	38,145	55,486	110,272	203,904
2033	59,526	86,067	163,169	308,762	70%	39,689	56,742	111,590	208,021
2034	60,905	88,768	165,101	314,774	70%	40,684	58,466	112,896	212,046
2035	62,266	91,587	167,066	320,918	70%	41,664	60,274	114,226	216,164
2036	63,610	92,894	167,375	323,878	70%	42,629	62,165	115,578	220,373
2037	64,938	94,330	167,693	326,962	70%	43,582	63,758	116,560	223,900
2038	66,253	95,788	168,022	330,063	70%	44,523	65,056	117,164	226,743
2039	67,555	97,267	168,360	333,182	70%	45,454	66,036	117,388	228,877
2040	68,845	98,767	168,707	336,319	70%	46,374	67,057	117,617	231,048
SUM	**For the years (2023 – 2035)**					**370,566**	**664,037**	**1,275,266**	**2,309,868**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 30: AfC data for the **HDS** scenario for LMT; **MDS** scenario for Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	Waste [tons]				POM target [%]	AfC volume to be collected (tons)			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	1,271	26,836	63,863	91,970	50.2%	1,215	17,547	71,838	90,600
2016	1,485	27,787	64,229	93,502	50.2%	1,485	19,363	72,146	92,994
2017	1,797	28,893	64,777	95,467	50.2%	1,931	21,148	72,183	95,263
2018	2,351	29,991	64,960	97,301	50.2%	2,622	22,884	72,062	97,567
2019	3,292	31,447	63,847	98,586	50.2%	3,575	24,558	71,888	100,020
2020	4,715	32,809	63,523	101,047	50.2%	4,776	26,176	71,723	102,676
2021	6,469	34,188	63,590	104,247	50.2%	6,265	27,746	71,578	105,589
2022	8,269	35,245	63,590	107,104	50.2%	8,038	29,254	71,542	108,833
2023	10,005	35,773	63,823	109,601	50.2%	10,052	30,665	71,674	112,391
2024	11,606	35,672	64,293	111,571	50.2%	12,252	31,941	71,984	116,177
2025	19,101	51,042	93,994	164,137	70.2%	14,578	46,224	101,349	162,151
2026	21,460	50,578	95,140	167,178	70.2%	16,978	47,505	102,199	166,682
2027	23,838	50,330	96,304	170,472	70.2%	19,409	48,519	103,196	171,123
2028	26,231	50,255	97,489	173,975	70.2%	21,837	49,291	104,303	175,432
2029	28,637	50,323	98,693	177,653	70.2%	24,241	49,873	105,492	179,605
2030	33,445	54,394	107,603	195,442	75.2%	26,605	53,913	114,346	194,864
2031	36,061	54,702	108,943	199,705	75.2%	28,818	54,338	115,719	198,875
2032	38,145	55,486	110,272	203,904	75.2%	30,812	54,782	117,113	202,706
2033	39,689	56,742	111,590	208,021	75.2%	32,570	55,303	118,520	206,393
2034	40,684	58,466	112,896	212,046	75.2%	34,099	55,939	119,939	209,977
2035	41,664	60,274	114,226	216,164	75.2%	35,411	56,712	121,369	213,492
2036	42,629	62,165	115,578	220,373	75.2%	36,525	57,619	122,700	216,844
2037	43,582	63,758	116,560	223,900	75.2%	37,461	58,643	123,855	219,959
2038	44,523	65,056	117,164	226,743	75.2%	38,243	59,761	124,814	222,817
2039	45,454	66,036	117,388	228,877	75.2%	38,895	60,947	125,591	225,433
2040	46,374	67,057	117,617	231,048	75.2%	39,441	62,180	126,216	227,837
SUM	(for the years 2023 - 2035)				**5.2%**	**307,662**	**635,005**	**1,367,202**	**2,309,869**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 31: POM data for the **LDS** scenario for LMT, Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	POM [tons]				POM target [%]	$POM_{3\ years}$ volume to be collected			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	3,946	63,188	148,576	215,710	45%	1,271	26,836	63,863	91,970
2016	4,723	66,883	143,471	215,076	45%	1,485	27,787	64,229	93,502
2017	7,004	69,867	141,017	217,888	45%	1,797	28,893	64,777	95,467
2018	10,220	72,899	141,159	224,278	45%	2,351	29,991	64,960	97,301
2019	14,206	75,964	141,308	231,478	45%	3,292	31,447	63,847	98,586
2020	18,703	79,060	141,464	239,227	45%	4,715	32,809	63,523	101,047
2021	19,129	78,499	138,851	236,479	45%	6,469	34,188	63,590	104,247
2022	19,549	75,752	137,576	232,878	45%	7,806	35,029	63,243	106,078
2023	19,993	73,199	136,363	229,555	45%	8,607	34,997	62,684	106,288
2024	20,455	71,068	135,209	226,732	45%	8,801	34,118	61,919	104,837
2025	20,932	69,284	134,112	224,327	65%	12,999	47,671	88,649	149,319
2026	21,420	67,787	133,067	222,275	65%	13,299	46,269	87,898	147,466
2027	21,919	66,531	132,074	220,524	65%	13,608	45,097	87,184	145,889
2028	22,425	65,478	131,128	219,031	65%	13,925	44,114	86,505	144,544
2029	22,938	64,597	130,228	217,763	65%	14,249	43,289	85,858	143,396
2030	23,458	63,863	129,372	216,693	70%	15,699	45,875	91,800	153,374
2031	23,666	64,892	129,406	217,964	70%	16,058	45,252	91,170	152,480
2032	23,878	65,996	129,453	219,327	70%	16,348	45,115	90,768	152,231
2033	24,093	67,169	129,512	220,774	70%	16,567	45,442	90,587	152,596
2034	24,310	68,405	129,585	222,301	70%	16,715	46,213	90,620	153,548
2035	24,531	69,702	129,670	223,902	70%	16,866	47,033	90,662	154,560
2036	24,753	69,840	128,482	223,075	70%	17,018	47,898	90,712	155,628
2037	24,977	70,004	127,317	222,298	70%	17,172	48,521	90,472	156,165
2038	25,204	70,186	126,174	221,564	70%	17,328	48,894	89,943	156,164
2039	25,432	70,381	125,052	220,865	70%	17,485	49,007	89,127	155,619
2040	25,662	70,585	123,951	220,198	70%	17,643	49,133	88,327	155,103
SUM	**For the years (2023 – 2035)**					**183,742**	**570,484**	**1,106,303**	**1,860,529**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 32: AfC data for the **LDS** scenario for LMT, Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	Waste [tons]				POM target [%]	AfC volume to be collected (tons)			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	843	31,292	141,758	843	47.4%	400	14,835	67,205	82,439
2016	1,051	34,698	142,606	1,051	47.4%	498	16,450	67,607	84,554
2017	1,485	38,091	142,978	1,485	47.4%	704	18,058	67,783	86,545
2018	2,253	41,432	143,030	2,253	47.4%	1,068	19,642	67,808	88,518
2019	3,542	44,685	142,920	3,542	47.4%	1,679	21,184	67,756	90,619
2020	5,204	47,846	142,747	5,204	47.4%	2,467	22,683	67,674	92,824
2021	6,797	50,915	142,391	6,797	47.4%	3,222	24,138	67,505	94,865
2022	8,191	53,855	141,844	8,191	47.4%	3,883	25,531	67,245	96,660
2023	9,400	56,606	141,143	9,400	47.4%	4,456	26,836	66,913	98,205
2024	10,476	59,102	140,322	10,476	47.4%	4,967	28,019	66,524	99,509
2025	11,472	61,273	139,411	11,472	67.4%	7,733	41,303	93,974	143,010
2026	12,422	63,063	138,441	12,422	67.4%	8,374	42,510	93,320	144,204
2027	13,348	64,433	137,437	13,348	67.4%	8,998	43,433	92,643	145,074
2028	14,259	65,371	136,418	14,259	67.4%	9,612	44,065	91,957	145,634
2029	15,157	65,898	135,403	15,157	67.4%	10,217	44,421	91,272	145,910
2030	16,038	66,065	134,402	16,038	72.4%	11,613	47,837	97,318	156,767
2031	16,913	65,954	133,482	16,913	72.4%	12,246	47,756	96,651	156,653
2032	17,771	65,668	132,688	17,771	72.4%	12,868	47,549	96,077	156,493
2033	18,600	65,309	132,038	18,600	72.4%	13,468	47,289	95,606	156,363
2034	19,388	64,966	131,531	19,388	72.4%	14,038	47,041	95,239	156,318
2035	20,128	64,705	131,156	20,128	72.4%	14,574	46,851	94,967	156,393
2036	20,816	64,560	130,810	20,816	72.4%	15,073	46,747	94,717	156,537
2037	21,452	64,539	130,411	21,452	72.4%	15,533	46,731	94,428	156,692
2038	22,036	64,628	129,917	22,036	72.4%	15,956	46,796	94,071	156,823
2039	22,572	64,811	129,314	22,572	72.4%	16,344	46,928	93,634	156,906
2040	23,064	65,063	128,603	23,064	72.4%	16,700	47,111	93,119	156,930
SUM	(for the years 2023 - 2035)				**2.4%**	**133,163**	**554,909**	**1,172,463**	**1,860,535**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 33: POM data for the **HDS** scenario for LMT, Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	POM [tons]				POM target [%]	$POM_{3\ years}$ volume to be collected			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	3,946	63,188	148,576	215,710	45%	1,271	26,836	63,863	91,970
2016	4,723	66,883	143,471	215,076	45%	1,485	27,787	64,229	93,502
2017	7,004	69,867	141,017	217,888	45%	1,797	28,893	64,777	95,467
2018	10,220	72,899	141,159	224,278	45%	2,351	29,991	64,960	97,301
2019	14,206	75,964	141,308	231,478	45%	3,292	31,447	63,847	98,586
2020	18,703	79,060	141,464	239,227	45%	4,715	32,809	63,523	101,047
2021	22,217	80,499	143,272	245,988	45%	6,469	34,188	63,590	104,247
2022	25,777	80,561	147,851	254,189	45%	8,269	35,328	63,907	107,504
2023	29,376	80,985	152,541	262,901	45%	10,005	36,018	64,888	110,911
2024	33,007	81,613	157,344	271,964	45%	11,606	36,307	66,550	114,462
2025	36,665	82,429	162,264	281,359	65%	19,101	52,684	99,176	170,962
2026	40,348	83,420	167,304	291,072	65%	21,460	53,089	102,299	176,848
2027	44,051	84,575	172,465	301,091	65%	23,838	53,617	105,498	182,952
2028	47,773	85,886	177,750	311,409	65%	26,231	54,259	108,774	189,263
2029	51,511	87,344	183,164	322,019	65%	28,637	55,008	112,129	195,774
2030	55,263	88,945	188,708	332,915	70%	33,445	60,155	124,455	218,055
2031	56,707	91,826	193,377	341,911	70%	36,061	61,174	128,245	225,480
2032	58,127	94,878	198,144	351,148	70%	38,145	62,560	131,891	232,597
2033	59,526	98,098	203,009	360,633	70%	39,689	64,318	135,387	239,394
2034	60,905	101,491	207,976	370,371	70%	40,684	66,454	138,724	245,862
2035	62,266	105,057	213,046	380,368	70%	41,664	68,709	142,130	252,502
2036	63,610	106,792	213,977	384,378	70%	42,629	71,084	145,607	259,320
2037	64,938	108,752	214,896	388,587	70%	43,582	73,113	148,166	264,861
2038	66,253	110,850	215,804	392,907	70%	44,523	74,807	149,781	269,111
2039	67,555	113,040	216,702	397,297	70%	45,454	76,159	150,425	272,037
2040	68,845	115,301	217,589	401,735	70%	46,374	77,617	151,061	275,051
SUM	**For the years (2023 – 2035)**					**370,566**	**724,350**	**1,460,145**	**2,555,061**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

Table S 34: AfC data for the **HDS** scenario for LMT, Rechargeable and Primary batteries EU27+3, 2015 – 2040

Year	Waste [tons]				POM target [%]	AfC volume to be collected (tons)			
	LMT	Rechargeable	Primary	TOTAL		LMT	Rechargeable	Primary	TOTAL
2015	1,193	37,470	143,774	182,437	51.1%	610	19,160	73,519	93,289
2016	1,475	41,216	144,318	187,009	51.1%	754	21,076	73,797	95,627
2017	2,199	44,863	144,283	191,345	51.1%	1,125	22,941	73,779	97,844
2018	3,449	48,384	143,927	195,760	51.1%	1,763	24,741	73,597	100,102
2019	5,468	51,764	143,500	200,733	51.1%	2,796	26,469	73,379	102,644
2020	7,776	55,024	143,133	205,933	51.1%	3,976	28,136	73,191	105,304
2021	9,915	58,177	143,055	211,148	51.1%	5,070	29,749	73,151	107,970
2022	11,990	61,192	143,684	216,866	51.1%	6,131	31,290	73,473	110,894
2023	14,158	64,008	145,217	223,382	51.1%	7,240	32,730	74,256	114,226
2024	16,495	66,573	147,638	230,706	51.1%	8,435	34,042	75,495	117,971
2025	19,019	68,855	150,828	238,702	71.1%	13,529	48,980	107,291	169,800
2026	21,717	70,854	154,632	247,204	71.1%	15,449	50,402	109,997	175,848
2027	24,574	72,606	158,904	256,084	71.1%	17,481	51,648	113,036	182,165
2028	27,572	74,172	163,525	265,268	71.1%	19,613	52,762	116,323	188,698
2029	30,694	75,631	168,410	274,734	71.1%	21,834	53,800	119,798	195,432
2030	33,925	77,060	173,501	284,486	76.1%	25,829	58,669	132,095	216,593
2031	37,123	78,525	178,660	294,307	76.1%	28,263	59,785	136,022	224,070
2032	40,206	80,079	183,794	304,079	76.1%	30,611	60,968	139,931	231,510
2033	43,153	81,751	188,876	313,780	76.1%	32,854	62,241	143,801	238,896
2034	45,958	83,562	193,917	323,437	76.1%	34,990	63,620	147,639	246,249
2035	48,623	85,529	198,943	333,095	76.1%	37,019	65,117	151,465	253,601
2036	51,150	87,649	203,537	342,336	76.1%	38,943	66,731	154,963	260,637
2037	53,539	89,890	207,429	350,857	76.1%	40,762	68,437	157,926	267,125
2038	55,793	92,213	210,579	358,585	76.1%	42,478	70,206	160,324	273,008
2039	57,918	94,582	213,066	365,565	76.1%	44,095	72,010	162,217	278,323
2040	59,919	96,966	215,023	371,908	76.1%	45,620	73,825	163,707	283,152
SUM	(for the years 2023 - 2035)				**6.1%**	**293,147**	**694,764**	**1,567,150**	**2,555,061**

(data in yellow is used to compute the correspondence between POM 3yrs to be collected volumes and the AfC alternative)

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