Stocks and Flows of Critical Materials in Batteries: Data Collection and Data Uses

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Abstract

ProSUM – Latin for “I am useful” – aims to provide better information on raw materials from secondary origins. It focuses in particular on the content of Critical Raw Materials (CRMs) from Batteries (BATT), Waste Electrical and Electronic Equipment (WEEE), End of Life Vehicles (ELV) and Mining Wastes (MIN) available for processing in Europe. Batteries are considered a highly relevant waste group in the ProSUM project due to the high content of CRMs. The main goal of this paper is to provide an overview of the data collection and data analysis for batteries and the materials they contain. In the research, it was necessary to develop a classification of batteries and build the inventory of available data on their stocks and flows. It includes the amounts of batteries put on the market, the stocks in households and businesses, and the flows of waste batteries collected and treated. The stocks and flows of batteries are linked with the average composition of the different types of batteries to calculate the stocks and flows of (critical) resources. The results are shown for lithium-based and NiMH batteries in laptops and tablets. The data made available are specifically useful when addressing current issues related to the European legislation for waste batteries, e.g. the definition of adequate targets for collection and the monitoring of recycling efficiency.

1 Introduction

Batteries and accumulators are chemical power systems which contain a variety of valuable elements needed to fulfill use and performance requirements. Nowadays, batteries depict one of the most relevant and challenging waste groups when considering critical raw materials. It is one of the product groups within the scope of the ProSUM project, funded by the European Union's Horizon 2020 research and innovation programme.

1.1 Background

The ProSUM project aims to establish a European network of expertise on secondary sources of CRMs, arising in waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELV), waste batteries (BATT) and mining wastes (MIN). It coordinates efforts to collect secondary CRM data and collate maps of stocks and flows for materials and products in the “urban mine”. Via a user-friendly, open-access Urban Mine Knowledge Data Platform (EU-UMKDP), it will communicate the results online and combine and relate them to primary raw materials data from the Minerals4EU project and the European Geological Data Infrastructure at large [1]. This knowledge base is aimed at policy makers at European and national levels, industry, and researchers to improve resource efficiency.

1.2 Objectives

This paper presents an overview of the available data sources on stocks and flows of batteries and their material content and provides the first results of the data consolidation. It identifies what is data treatment is necessary to obtain suitable information to support possible policy making decisions for a sustainable management of batteries.

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2 Method for data collection and analysis

In order to facilitate proper data collection and analysis, the classification and inventory of battery data on its stocks and flows was undertaken. This included the different amounts of batteries put on the market (POM), stocks in households and businesses and the flows of waste batteries collected and treated. Complementary flows that include batteries waste in municipal solid waste and embedded in WEEE were also analysed in this project. Data from different sources can be inconsistent and is often not harmonised, therefore there is the need for it to be consolidate it in ways which limit uncertainty. The stocks and flows of batteries were linked with the average composition of the different types of batteries in order to calculate the stocks and flows of (critical) resources. This considered the mass fraction of cobalt in various lithium-ion battery types and of other rare earth elements found in nickel-metal hydride batteries.

3 Data sources

3.1 Composition of batteries

Data on the composition of batteries was available from the following sources, each having strengths and weaknesses:

- Global reference documentation, such the “handbook” of Linden [2], providing relatively accurate information, mainly about generic battery types.
- Scientific literature with analysis of products like Sommer et al. [3], providing detailed composition of batteries. Nevertheless, with such products it is more difficult to identify if the product analysed is representative of the main stream.
- Safety information: many manufacturers provide “Material Safety Data Sheets” (MSDS) or equivalent documents like [4]. These MSDS provide validated sources of information but with generally a low level of precision.
- Battery Composition information (Bill of Material) used for environmental studies like the one conducted by BIO IS [5].
- Various other sources, such as specific information from the battery industry associations.

3.2 Data sources to quantify the stocks and flows

Currently, there are six types of organisations that have and partly publish data on stocks and flows of waste batteries.

3.2.1 Eurostat

At a European level, the statistical office of the European Commission, Eurostat, provides data on batteries POM and collected in tonnes and kg per inhabitant, in which different types of batteries are not distinguished [6]. Furthermore, the statistics on the production of manufactured goods (ProdCom [7]) make data available on products sold in, exports and imports from and to the EU member states as well as Iceland, Norway, and Turkey for the four categories of batteries.

3.2.2 National authorities

Some countries like France publish national statistics on the weights of batteries POM, collected as waste and on the recycling efficiency, and distinguish different types of batteries.

3.2.3 Consultancies

Every year, consultancy companies like Avicenne publishes market data at the Battery Congress in Nice (France) and makes a commercial report available [8].

3.2.4 Compliance schemes

Depending on the national legislation, compliance schemes (e.g. the German GRS Batterien Foundation [9]) may publish data on the weights of batteries POM and collected as waste, as well as data on recycling efficiency.

Data on stocks of batteries were compiled by the organisations Bebat for Belgium, Corepile for France and Stibat for the Netherlands through surveys of households.

3.2.5 Industrial associations

The industrial associations Eucobat [10], Eurobat [11], [12] and EPBA [13] collect and compile data on batteries POM and collected. Some of the data are publicly available and others are confidential.

3.2.6 Operators of sorting and recycling facilities

The operators collect raw data, i.e. the mass of the input and output fractions to and from their facility, quantitative and qualitative results of analyses of the composition, and quality of these fractions etc. These data sets are usually confidential. They are aggregated and compiled to fulfil the reporting requirements of the compliance schemes and/or authorities set in the EU Battery Directive.

4 Results

4.1 Classification of batteries

Batteries are used in products or connected to products as uninterrupted power supplies. They can be sold separately, be embedded in vehicles and electrical and electronic equipment (EEE), or within the electronics embedded in vehicles. Several classification approaches for batteries exist, depending on cell chemistry, hazardousness, chargeability, and area of application.

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 was developed. The battery types cover the six current main electrochemical systems based on lithium, zinc, nickel-cadmium, nickel-metal hydride, lead and others. The six battery types were further divided into 16 BATT keys as displayed in Table 1. These keys are compatible with classifications by chargeability type, the Battery Directive descriptions, battery recycling flows and other trade codes such as the EU List of wastes, ProdCom, the Combined Nomenclature (CN), as well as the United Nations Committee of Experts on the Transport of Dangerous Goods.

Table 1: The BATT keys based electrochemical subsystems (BATT_key code list)

BATT keys	Name
BattLiCoO2	Lithium cobalt dioxide ($LiCoO_2$)
BattLiFePO4	Lithium iron phosphate ($LiFePO_4$)
BattLiMn	Lithium manganese (LiMn)
BattLiMnO2	Lithium manganese dioxide ($LiMnO_2$)
$BattLiCF_x$	Lithium carbon monofluoride ($LiCF_x$)
BattLiNMC	Lithium nickel manganese cobalt (LiNMC)
$BattLiSO_2$	Lithium sulfur dioxide ($LiSO_2$)
$BattLiSOCl_2$	Lithium thionyl chloride ($LiSOCl_2$)
BattNiCdSealed	Nickel cadmium (NiCd), sealed
BattNiCdVented	Nickel cadmium (NiCd), vented
BattNiMHSealed	Nickel metal hydride (NiMH), sealed
BattNiMHVented	Nickel metal hydride (NiMH), vented
BattPbSealed	Lead-acid (Pb), sealed
BattPbVented	Lead-acid (Pb), vented
BattZn	Zinc
BattOthers	Others

4.2 Description of the stocks and flows of batteries

To understand the flows, a system flow diagram was depicted (Figure 1). Portable batteries can be sold either incorporated in business or consumer appliances, or as single cells. Depending on use, lifespan, and consumer behaviour, batteries reside used or unused in the urban stock. Waste batteries may be disposed of legally or illegally via: a) a public or private battery collection scheme; b) collection scheme for WEEE; c) collection with other waste streams, like residual waste; or d) direct disposal into the environment. The collection of industrial batteries is done either by the collection scheme for portable batteries or through individual contractual schemes. Automotive batteries, for instance lead acid, are collected by specific take back systems.

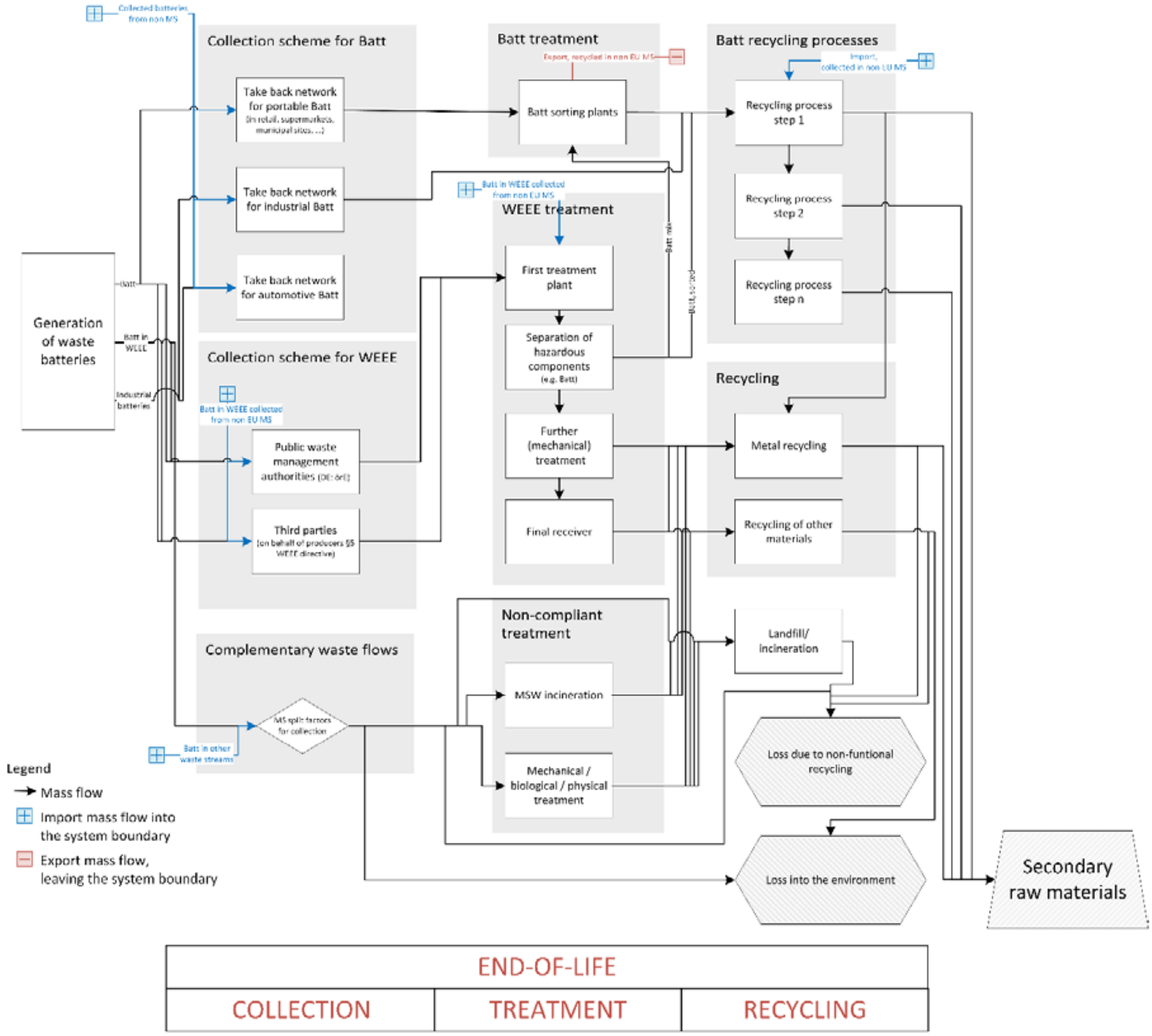

Figure 1: System description for batteries

4.3 Stocks and flows of batteries

The case study of laptop and tablet batteries was selected as an example to illustrate the preliminary results of the stocks and flows modelling with no uncertainty consideration so far.

A preliminary analysis of the Avicenne data [8] by Recharge focused on the batteries POM in laptops and tablets in the European Union (EU) between 1998 and 2014. Figure 2 shows the estimated amounts of $LiCoO_2$, Li-NMC and Ni-MH batteries POM in laptops and tablets (Figure 2, in million units per year).

Data on the age of collected waste batteries (lifespan from production to collection in Belgium in 2012) were presented by Bebat at the International Congress for Battery Recycling [14], showing the lifespan of a large sample of 17,000 waste batteries with a known production date collected in Belgium in 2012. For lithium rechargeable batteries, contained in 4 products types, the probability density function that best fits the experimental data was determined using a Weibull distribution. It revealed a preliminary median lifespan for 102 sampled waste batteries from laptops of 9.8 years. For tablets, a median lifespan of 6.1 years as measured for mobile phones batteries was assumed. The median age of collected waste batteries is expected to decrease.

For the years after 2014, the preliminary assumption, which will be improved in the future research, was that the market stays stable, i.e. the POM volumes of 2014 were used for the years 2014-2020. Modelling based on the POM and the lifespan distribution provided estimates of the volumes of waste batteries generated until 2020, in million units per year (Figure 3).

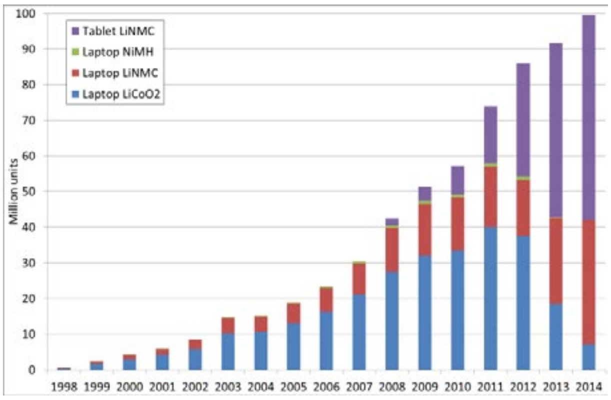

Figure 2: Volumes of $LiCoO_2$, Li-NMC and Ni-MH batteries POM in the EU between 1998 and 2014 in laptops and tablets

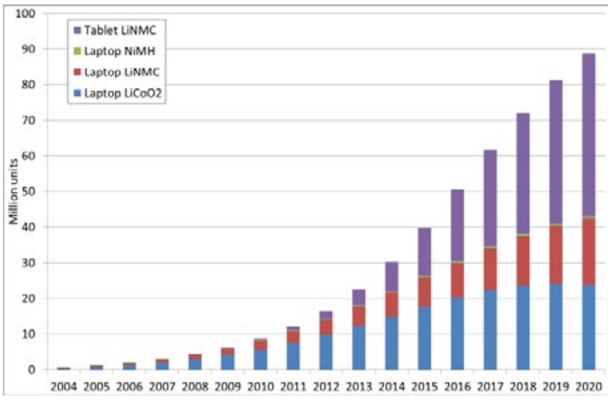

Figure 3: Estimated volumes of $LiCoO_2$, Li-NMC and Ni-MH waste batteries from laptops and tablets generated in the EU between 2004 and 2020

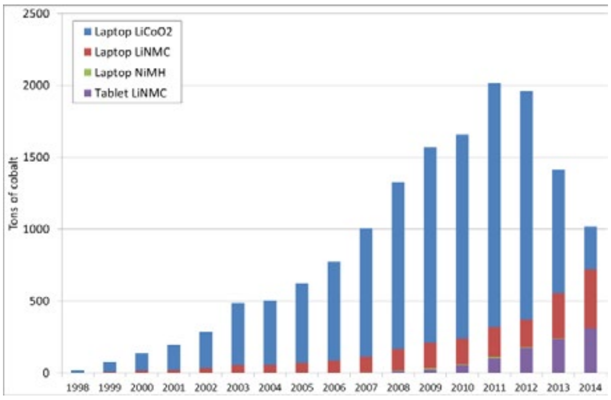

Figure 4: Cobalt embedded in $LiCoO_2$, Li-NMC and Ni-MH batteries POM in the EU between 1998 and 2014 in laptops and tablets

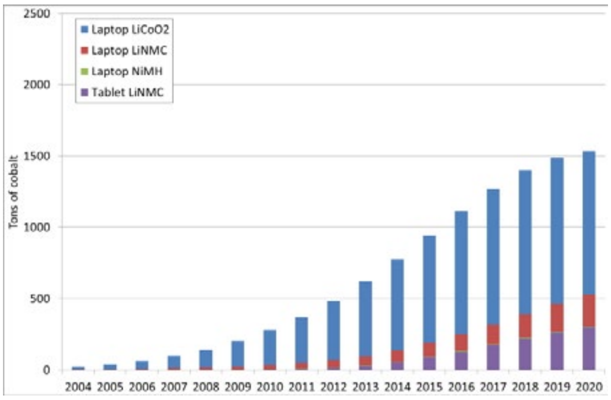

Figure 5: Cobalt embedded in the estimated volumes of $LiCoO_2$, Li-NMC and Ni-MH waste batteries from laptops and tablets generated in the EU between 2004 and 2020

In the ProSUM research, the estimates of waste batteries generation are compared to the data on collected waste batteries to check if the collected volumes match the estimates on waste generation. An analysis of the complementary flows for batteries conducted within ProSUM showed that waste batteries are found in municipal waste, in separately collected WEEE and in exports of used EEE and WEEE [15]. Compared to 72,000 tonnes of portable waste batteries reported as having been separately collected in the EEA area plus Switzerland in 2011 [13], the identified complementary flows range between 150,000 and 540,000 tonnes of waste batteries in 2012 [15].

4.4 Stocks and flows of CRM

In this paper, a case study for cobalt is presented. The data on the POM volumes and the estimates of the waste generation were converted from units into weight by multiplying with an average weight of the batteries. These flow volumes in tonnes were then multiplied with average concentrations of cobalt in $LiCoO_2$ (14%), Li-NMC (4%) and Ni-MH (3%) batteries [16], again without considering the uncertainties.

Figure 4 shows that the amount of cobalt embedded in the batteries POM in the European Union increased until 2013, and decreased in the following years due to the technology shift from the cobalt-rich $LiCoO_2$ electrochemical system to Li-NMC.

Figure 5 shows the estimated amount of cobalt in the generated waste batteries. The total content of embedded cobalt keeps increasing until 2020.

5 Discussion on policy level

The data made available are specifically useful when addressing two current issues related to the European legislation for waste batteries: the first one being the definition of collection targets, and the second one concerning the definition of targets for recycling efficiency and the relevance of mass-based targets.

5.1 Use of data to define collection targets

The Batteries Directive [17] stipulates that the EU Member States shall achieve the minimum collection of 45 % by 26 September 2016. The collection rate has been calculated since 2011 as:

$$CR_n = \frac{3 \times C_n}{S_{n-2} + S_{n-1} + S_n} \qquad (1)$$

with: CR_n: Collection rate in year n
C_n: Collection in year n
S_n: Sales in year n

Formula 1 applies to all portable batteries. It was applied in the case of batteries from laptops and tablets for the year 2014, with the (unrealistic) assumption that all generated waste batteries are collected:

$$MR_{2014} = \frac{3 \times G_{2014}}{S_{2012} + S_{2013} + S_{2014}} = 39\ \% \qquad (2)$$

with: MR_n: Modelled rate in year n
G_n: Estimate of the waste batteries generation in year n

For growing markets as it is the case for laptops and tablets, according to the modelling results, in 2014 a collection target of 45 % would not have been possible, because the weight of waste batteries that would have had to be collected exceeds the total estimated generation volumes.

A quick sensitivity analysis shows that if a median lifespan of 6.1 years (instead of 9.8 years) as measured for mobile phones is assumed for waste batteries from laptops and tablets, the MR_{2014} would be 64%. In this case, a collection target of 45% could be achievable.

In the case of the NiCd batteries, which market share is decreasing, collection targets calculated with formula 1 would be very low due to the very low POM volumes.

These calculations complement the conclusions of the report commissioned by EPBA [13], which questions the relevance of collection rates as a measure of scheme performance and concludes that “the 45% target in 2016 remains a challenge”. A possible shift of the target definition mentioned in a working document of the European Commission [18] could be to express collection targets as a ratio of the amount of batteries available for collection instead of the amount of batteries put on the market. A similar change is already progressing for WEEE with the common methodology report [19] proposing an alternative WEEE generated target.

The results confirm that a more comprehensive analysis based on robust data differentiated according to the products in which they are embedded and to the battery types is needed to provide “a more realistic assessment of the performance of a portable battery collection scheme” [13] and a scientific basis to define “ambitious but realistic” targets that incentivise the improvement of the collection of batteries [13].

5.2 Use of data to define targets for recycling efficiency

Mass-based targets encourage the recycling of materials with a large mass share and may hamper the recycling of materials with a low mass share, but more likely to be associated with high environmental impacts, classified as critical, and/or with a high economic value.

A view into the complex material composition of modern batteries shows that the definition of fix mass-based targets for recycling efficiency in the Batteries Directive, which only differentiates three battery chemistries, can hardly differentiate and/or encourage the use of innovative treatment processes. A 50% target applies for all “other batteries”, which include all types of lithium-ion, NiMH and alkaline batteries.

According to preliminary data [18] and treatment trials carried out by TU Berlin, it is technically not possible for some electrochemical systems to achieve the 50% target. However for others, the rate can be achieved but valuable substances are lost. In contrast to e.g. alkaline batteries which consist mainly of iron (especially steel sleeves), manganese, and zinc (in total >55%), systems such as lithium batteries or Ni-MH depict an economic, ecological and technological challenge. The CRM containing active materials constitute a mix of substances with increasing heterogeneity that is hard to recycle efficiently and economically. Designs like coffee bag systems (pouch cells) may hamper the achievement of fix mass-based target.

Therefore, the establishment of recycling efficiency targets may require a careful review of feasibility and a clear description of the policy expectations to promote quality recycling in Europe. This means that the targets would need to be revised based on data on the composition of the waste batteries. They need to be differentiated according to the electrochemical systems available on the market and defined based on data on the treatment processes for waste batteries from different countries, because “the recycling playing field is not a level one across the EU” [20]. Consequentially, also the method to calculate the recycling efficiency should be revised.

6 Conclusions

The preliminary results on the case studies show trends related to the flows of battery from laptops and tablets and to the related flows of the CRM cobalt. Due to the fast market changes, the year on year variations are very significant. The next steps of the research include the selection and consolidation of the data from the different sources, as well as the evaluation of the data quality and the quantification of the uncertainties using a harmonised method common to all product flows considered in ProSUM [1].

The importance of basing decision support and policy making on solid data is acknowledged by the European Commission, which commissions research projects and launches activities to improve the data availability. However, so far this is not always reflected in the legislation in place, and will require further effort in the future, as the complexity and fast evolution of the batteries market and end-of live flows make it difficult to get access to the relevant data.

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Literature

[1] J. Huisman, H. Habib, M. Guzman Brechu, S. Downes, L. Herreras, A. Loevik, P. Wäger, D. Cassard, P. Mählitz, V. S. Rotter, M. Ljunggren Söderman, and P. Chancerel, "ProSUM: Prospecting Secondary raw materials in the Urban mine and Mining wastes. Systematic harmonisation and classification of data sources for mapping EU secondary raw materials in Electronics, Batteries, Vehicles and Mining Waste," in *Proceedings Electronics Goes Green 2016+*, 2016.

[2] D. Linden, "Handbook of batteries." McGrow-Hill handbooks, Third edition, Worldwide, 2001.

[3] P. Sommer, V. S. Rotter, and M. Ueberschaar, "Battery related cobalt and REE flows in WEEE treatment," *Waste Manag.*, 2015.

[4] Saft, "Battery Information Sheet, Rechargeable lithium-ion cells, modules and battery systems." 2014.

[5] BIO IS, "Comparative LCA (Life Cycle Assessment) of NiCd batteries used in Cordless Power Tools (CPT) vs. their alternatives NiMH and Li-ion batteries." European Commission - DG Environment, 2011.

[6] Eurostat, "Generation of Batteries and accumulator wastes (WStatR)." European Commission, 2015.

[7] Eurostat, "Statistics on the production of manufactured goods (PRODCOM)." European Commission, 2016.

[8] Avicenne, "Battery Market Development for Consumer Electronics, Automotive, and Industrial." Batteries congress, Worldwide, 2015.

[9] GRS Batterien, "Annual review 2014." Stiftung Gemeinsames Rücknahmesystem Batterien, 2015.

[10] Eucobat, "Key figures." Eucobat, 2016.

[11] Eurobat, "Industrial Batteries Economic Outlook." Eurobat, 2013.

[12] Eurobat, ACEA, JAMA, KAMA, and ILA, "The availability of automotive lead-based batteries for recycling in the EU." 2014.

[13] Perchards, "The collection of waste portable batteries in Europe in view of the achievability of the collection targets set by Batteries Directive 2006/66/EC." European Portable Battery Association (EPBA), 2015.

[14] BEBAT, "How the battery life cycle influences the collection rate of battery collection scheme." International Congress for Battery Recycling (ICBR), 2014.

[15] A. Wolk-Lewanowicz, K. James, J. Huisman, H. Habib, M. Brechu, L. Herreras, and P. Chancerel, "Assessment of Complementary Waste Flows. Deliverable 3.2 of ProSUM project." 2016.

[16] C. Chanson, "Manufacturers information compiled in the RECHARGE database." ProSUM project, funded from the European Union's Horizon 2020 research and innovation programme, 2016.

[17] European Parliament and the Council of the European Union, "Directive 2013/56/EU of the European Parliament and of the Council of 20 November 2013 amending Directive 2006/66/EC of the European Parliament and of the Council on batteries and accumulators

and waste batteries and accumulators as regards the placing on," *Official Journal of the European Union*. 2013.

[18] European Commission, "Ex-post evaluation of Five Waste Streams Directives - Commission staff working document." 2014.

[19] F. Magalini, F. Wang, J. Huisman, R. Kuehr, K. Baldé, V. Van Straalen, M. Hestin, L. Lecerf, U. Sayman, and O. Akpulat, "Study on collection rates of waste electrical and electronic equipment (WEEE)." European Commission, 2016.

[20] M. Green, "Taking Account of Legislation," in *ColaBats Newsletter 05 May 2016*, 2016, p. 4.