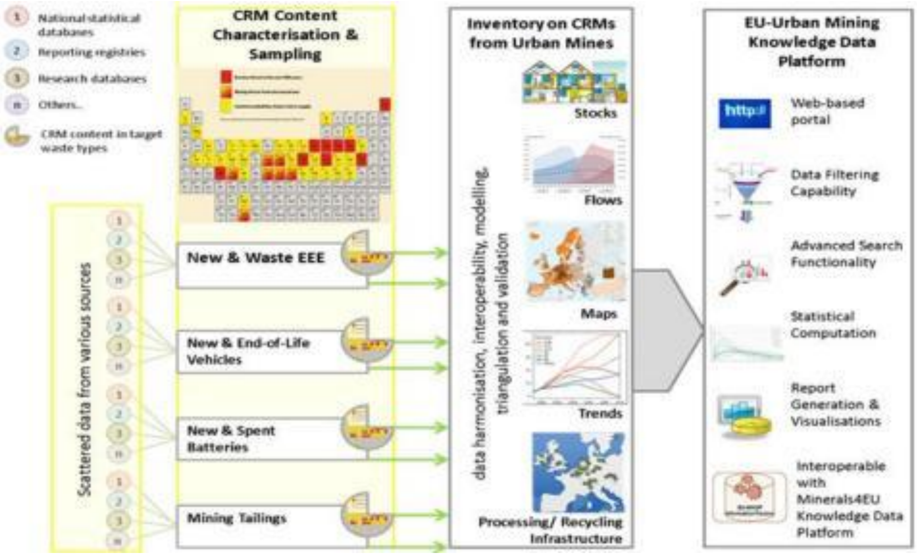
Screen available data on CRM parameters in products and components Deliverable 2.2.



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NOTICE

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BATT – Batteries

CRM – Critical raw material

EEE – Electrical and electronic equipment

ELV – End-of-life vehicle

IDIS – International Dismantling Information System

IMDS – International Material Data System

LCA – Life cycle analysis

MSDS – Material safety data sheets

WEEE – Waste electrical and electronic equipment

PURPOSE

This document describes the results of the activities undertaken in Task 2.1.1 to characterise CRM parameters by screening of the available data on CRM parameters in products and components. In this report CRM parameters means parameters that can be used to describe or calculate the chemical composition of products and components with respect to CRMs. The work in Task 2.1.1 relies on the framework of classification and code lists that were developed in Deliverable 5.3 on harmonisation, especially the product keys, component list and material list. In addition to these code lists, a list of CRM parameter labels is established within 2.1.1 to enable a precise description of the property represented by the numeric data contained in references. Data sources are uploaded to a shared EndNote library and described using the code lists from D5.3. The data source references include scientific journal articles, conference papers, and reports from industry associations, government institutions, consultancies and private companies. The CRM data collated forms part of the total data inventory for the project and contributes to Milestone 4 "Existing Data Inventory".

EXECUTIVE SUMMARY

Data on CRM parameters were identified in scientific literature and grey literature e.g. industry reports. The general availability of CRM parameter data is moderate, and highly dependent on the type of product, component and element considered. It can be concluded that in general the focus with regards to CRM is on products and components containing a high weight% of CRMs. CRM data are usually available at the element level, while bulk materials data are typically at the material level (i.e. as alloys). The most commonly studied elements are aluminium, copper, iron, cobalt, neodymium and nickel. The least commonly studied elements are natural graphite, osmium, and iridium.

The data availability for products defined in the ProSUM code lists can be characterised as high for batteries (around 50 sources), medium for EEE (around 60 sources) and low to medium for vehicles (around 30 sources). The ProSUM project has defined product categories based on keys, aligned with the UNU keys for WEEE (see Deliverable 5.3). For batteries, most of the defined keys (e.g. battery types) are well covered with composition data. For EEE, there are a large number of studies on the composition of a few specific keys, especially mobile phones, personal computers and TVs, but many of the defined keys have very little data available. For vehicles the least data has been identified, however some important variations are covered, such as the difference between conventional, hybrid and electric cars. However, the stock and flows information is not configured to represent the composition differences very well.

The lack of CRM parameter data for many product keys and components is the most important issue to address in the continuation of this work. There are at least three possible ways of dealing with this: i) a continued search for data; ii) estimation based on existing data for other product keys and components; or iii) narrowing down the scope, for example by aggregating keys to a higher level. In general, it is expected (based on the experience gained during this ProSUM task) that a combination of the three will be required. The second important issue to deal with is the availability and relevance of data on products or components which are currently not covered by the ProSUM code lists. This could be addressed by expanding the code lists, but it is important to make sure that such expansion also makes sense considering the availability of data on stocks and flows. A third important issue to deal with is the inconsistency between terminology used in literature and the code lists defined within ProSUM. It is sometimes difficult, especially on the material and component level, to accurately describe the references, for example because measurements have been done on a component which defined differently than in the ProSUM components list.

The data screening in Task 2.1.1 conducted using an EndNote library (the ProSUM bibliography), currently containing 336 references, of which around 120 contain data on CRM parameters. In the continuation of the work in the ProSUM project, this database will be continuously expanded with new references as they become available, as part of Task 2.1.2, 2.1.3 and 2.2. and the other Tasks that use data-sources, databases and other external sources for assessing the CRM content in products and components, CRM stocks & flows, wastes etc. The ProSUM bibliography is specifically set-up to be able to categorise, filter and manage the continuously growing knowledge base behind the EU-Urban Mine Knowledge Data Platform.

1. INTRODUCTION

1.1. Aim and scope

The aim of this deliverable is to screen data on CRM parameters in products and components via data mining. CRM parameters are parameters that can be used to describe or calculate the composition of products and components with respect to CRMs. Screening involves gathering references containing CRM parameter data and for each reference describing which CRM parameters it contains data on and which product keys, components, materials and elements these CRM parameters relate to. Deliverable 2.2 concerns a part (T2.1.1) of Task 2.1 of the Technical Annex 1 of the ProSUM Grant Agreement (see Figure 1).

The scope of this deliverable specifically comprises CRM parameters in electrical and electronic equipment (EEE), battery (BATT), and vehicle components and products. It complements the scope of the parallel deliverables 3.1 (product market inputs and stocks) and 4.1 (waste generation and available waste flow studies). A single inventory has been developed in practice, as multiple sources may have multiple data points in these three flows, and there is a requirement to link the WP 2, 3 and 4 data carefully.

In line with the scope of the ProSUM project, data mining will address component/product composition relevant for the EU28 plus Switzerland + Norway and the time period from 1980-2015. In accordance with the description of Task 2.1 in Annex 1 of the ProSUM Grant Agreement, data mining is based on literature, existing open source databases and interviews where required.

The CRMs addressed in Deliverable 2.2 correspond to the CRMs defined as critical to the EU, and when data was easily accessible the additional elements defined to be within the scope of ProSUM (cf. section 7.4 and Annex 5 in D5.3).

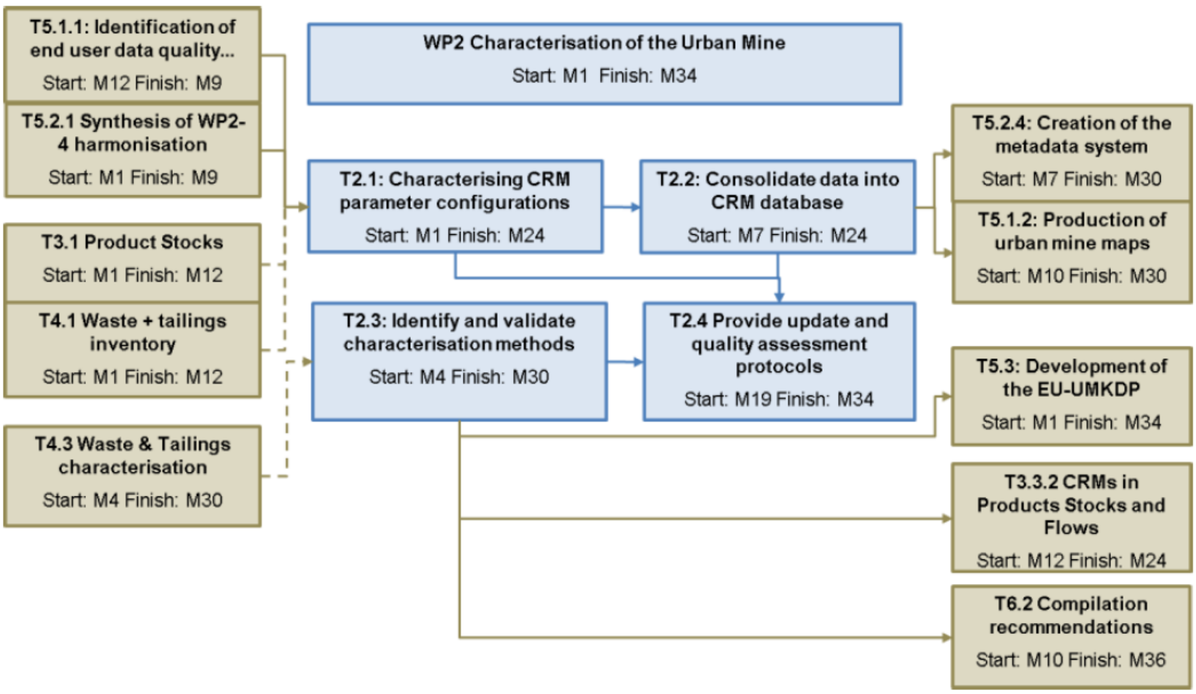

Figure 1: Work Package 2 Pert Chart.

1.2. Classification and data formats

The work for Deliverable 2.2 relies on the framework of classification and code lists that were developed in Deliverable 5.3 "Review and harmonisation of data", especially the product keys, component list and material list. In addition to these code lists, a list of CRM parameter labels has been established to enable a precise description of the property represented with numeric data contained in references (see section 2. Methods).

2. METHODS

The methods selected to screen available data on CRM parameters in EEE, BATT and vehicles components and products were (i) review of scientific publications on CRM Parameters, (ii) review of "grey literature" on CRM Parameters and (iii) review of official statistical databases, supplemented with interviews where required. The starting point for the reviews was the bibliographies of the ProSUM research partners, which was extended with a search in scientific literature databases and publicly available reports and databases.

The results of the reviews were entered in the ProSUM bibliography described in the Deliverable 5.3 report (section 10.2). For a detailed description of how the data sources and their meta-data descriptors were entered into the general bibliography file, see (ANNEX 1 – MANUAL FOR ENTERING DATA SOURCES INTO THE PROSUM BIBLIOGRAPHY).

To enable CRM parameter data entry, the metadata field "CRM parameters" which was introduced in the D5.3 report (section 10.2) had to be further specified. In order to do so, a set of CRM parameter codes for describing or calculating the composition of components and products was defined based on the hierarchical conceptualisation of products and their constituents, as illustrated in Figure 2. A product (e.g. a dishwasher) is composed of a set of components; each component is composed of a set of materials; each material is composed of chemical elements. The primary goal is to describe the composition of each product in terms of the CRMs it contains, e.g. as grams of gallium per laptop computer, or grams of gallium per kg of laptop computers. There are many possible ways of arriving at such a number, and due to the variety of data available, it is necessary to define a set of parameters that gives a certain degree of flexibility with respect to quantification method.

In some studies, the product composition is given directly on the elemental level (chemical composition), but often the data is only available for selected components (e.g. the hard disk of a personal computer) or on the material level rather than element level. A common example is aluminium metal, which usually refers to a metallic alloy containing up to 25% other elements rather than the pure element aluminium. Such partial data on component and material level can then be combined to arrive at an estimate of the chemical composition of the product.

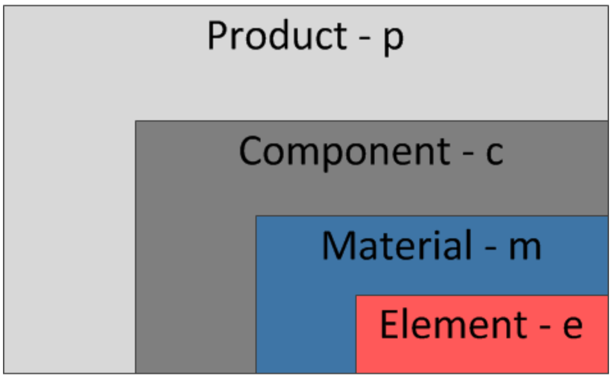

Figure 2: Hierarchical conceptualisation of products, components, materials and elements, which forms the basis for the set of CRM parameters.

The CRM parameters, or rather CRM parameter labels, are given as a single letter, *u,* or a combination of two letters v-*w*. A single letter u indicates data on an extensive[1] property for the entity designated by *u*. It is only relevant for components and products, since a material or element does not have extensive properties. For example, data on the mass of dishwashers might be of interest, and would be labelled *p* for product. It is also possible to provide other extensive properties, such as the area of an integrated circuit, which would be labelled *c*. A combination of two letters indicates an extensive or intensive property (usually mass or mass fraction) of an entity *v* in another entity *w*. An example is *e-c*, which indicates that the data is on the total mass of an element per component (e.g. g/piece) or the mass fraction (e.g. mg/kg) of an element in a component. The current list of CRM parameters is:

e-m: Mass or mass fraction of an element in a material
e-c: Mass or mass fraction of an element in a component
e-p: Mass or mass fraction of an element in a product
m-c: Mass, mass fraction or volume of a material in a component
m-p: Mass, mass fraction or volume of a material in a product
c-c: Mass, mass fraction, number, length, volume, area or other extensive property of a component in another component
c-p: Mass, mass fraction, number, length, volume, area or other extensive property of a component in a product
p-p: Mass, mass fraction, number, length, volume, area or other extensive property of a product in another product
p: Mass, length, area, volume or other extensive property of a product
c: Mass, length, area, volume or other extensive property of a component

Note that *c-c*, and *p-p*, are also valid options, since a product (e.g. battery) may sometimes appear as a component of other products, and a component can often be subdivided into yet other components. For example, a populated printed circuit board and its capacitors are both considered components in this system.

The labels only indicate which entities are included in the data, not which property is represented. Thus, further specification could be used to completely define the parameters. For example, $x_{e\text{-}c}$ could be used to represent the mass fraction of element *e* in component *c*, and X_c could represent the mass of component *c*. Using this notation, we can calculate the mass fraction of an element *e* in a product *p,* $x_{e\text{-}p}$, by several methods, for example:

$$x_{e-p} = \frac{\sum_c x_{e-c} X_c}{\sum_c X_c}$$

where the sums cover all the components constituting the product. Another option to calculate the same parameter, $x_{e\text{-}p}$, is:

$$x_{e-p} = \sum_m x_{e-m} \, x_{m-p}$$

where the sum covers all the different materials contained in the product.

[1] An extensive property is one that depends on the size of the system, e.g. mass, length or volume. An intensive property is one that is independent of the size of the system, e.g. mass fraction, concentration or modulus of elasticity.

3. RESULTS & DISCUSSION

The CRM parameters encountered in the available data are presented in the following three sections for batteries, vehicles, and EEE, respectively.

3.1. Batteries

The selected data used to assess the CRM content of batteries are presented in
. Contrary to others product flows such as EEE or vehicles, there is a lot of available information on the chemical composition of batteries. This information comes from various fields of activities or interest, but is generally facilitated by the fact that batteries are considered as a whole entity with a specific composition: the output of a single manufacturing process. However, the available data lacks information about the electronic part of the batteries. New types of chemistries, such as the lithium batteries technologies, require an electronic control associated (so-called "battery management system"). These electronic components are very often not considered when assessing the CRM parameters of a battery. This limitation can be compensated for when using the more complete data presented for environmental studies (such as the Bill of Materials used for Life Cycle Analysis (LCA)).

The type of information selected is extracted from the following sources, each having strengths and weaknesses:

- Global reference documentation, such as "handbooks", providing relatively accurate information, mainly about the generic type of batteries.
- Scientific literature with analysis of products, providing detailed composition of batteries. Nevertheless, with such products it is more difficult to identify if the analysed product is representative of the main stream.
- Safety information associated to the products: although batteries are considered as articles, and not as a container of substances under the REACH regulation, many manufacturers provide "Material Safety Data Sheets" (MSDS) or equivalent documents. 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.
- Various other sources, such as specific information from the battery industry associations.

The type of information varies but most of it provides information as e-p (mass fraction of an element in a product), allowing an easier comparison between several sources.

Table 1: Occurrence of CRM Parameters in Data-sources on Batteries. Green: reference contains data on specified CRM parameter. Red: reference contains no data on specified CRM parameter.

Author	e-m	e-c	e-p	m-c	m-p	c-c	c-p	p-p	p	c
Arts Energy, (2014)	X	x	x							
Arts Energy, (2014)	x	x	x							
Buchert, M., D. Schüler and W. Jenseit (2010)			x		x					
Chancerel, P., V. S. Rotter (2013)		x								
Cobasys, (2015)	x	x	x							
East Penn Manufacturing Company, (2007)	x	x	x							
East Penn Manufacturing Company, (2015)	x	x	x							
Ellis, T. W. and A. H. Mirza, (2011)			x							
EnerSys, (2013)	x	x	x							

EnerSys, (2013)	x	x	x							
EPTA (PE), (2009)	x	x	x							
Eucobat, (2016)									X	
Ford-Umicore, (2009)	x	x	x							
Habib, K., H. Wenzel (2014)		x	x							
Informations-Portal-Abfallbewertung, H. Vertreter aus den Bundesländern Baden-Württemberg, Niedersachsen, Nordrhein-Westfalen, Rheinland-Pfalz, Sachsen und Sachsen-Anhalt (2016)			x							
Jody, B., E. Daniels (2007)			x							
Labie, R., G. Willems, D. Nelen and K. Van Acker (2015)			x		x					
Linden, D., T. B. Reddy (2001)			x		x					
Mudgal, S., Y. L. Guern, B. Tinetti, A. Chanoine, S. Pahal and F. Witte (2011)		x								
Notter, D. A., G. M, W. R, W. P et al. (2010)	x	x	x							
Saft, (2008)	x	x	x							
Saft, (2010)	x	x	x							
Saft, (2010)	x	x	x							
Saft, (2012)	x	x	x							
Saft, (2012)	x	x	x							
Saft, (2014)	x	x	x							
Schischke, K., N. F. Nissen, L. Stobbe, M. Oerter et al. (2014)							x			
Sommer, P., V. S. Rotter and M. Ueberschaar (2015)	x	x	x							
Ultralife, (2013)	x	x	x							
United States Environmental Protection Agency, S. Amarakoon, J. Smith and B. Segal (2013)	x	x	x							

Based on the available data, the CRM content for batteries should be relatively complete concerning the main streams. In addition, various niche market batteries with specific chemistries are placed on the market in limited quantities in Europe. They have not been taken into account in this deliverable, as no statistical information has been identified which will allow for assessing what amount of CRM they represent.

The main difficulty remains in the comparison of the data sources to correctly assess the composition range and uncertainty for the selected categories identified by the battery keys. The granularity of the battery keys has been decided in such a way that it allows for a direct comparison between the CRM parameters of batteries placed on the market and the CRM parameters measured at collection and recycling stage. As a result, we have various types of battery chemistries represented in the same battery key, and this leads to an increased range of possible compositions, reducing the CRM parameter accuracy. Nevertheless, an assessment of the representative composition will be made based on the market studies indicating the battery technologies used per application.

Finally, the change in battery composition over years is difficult to trace in the published data. Nevertheless, it can be observed that one of the main drivers for the battery technology evolution is the change in the application of the battery. An example can be provided with the market change from laptop computers to tablets. The main battery type used for the laptop computers is a small standard cylindrical type but this product cannot be used for tablets. Due to their flat format, they only use flat battery types. These two different types of lithium–ion batteries have different chemistries and the CRM composition of the batteries in these applications can therefore be assessed based on the available market share data of laptops and tablets over years. The composition change in the same battery technology over years is negligible in comparison.

3.2. Vehicles

The availability of composition data for vehicles is summarised in
. Among the reviewed references, 17 were found to contain relevant data on the composition of passenger vehicles. These references include 8 papers from scientific journals or conferences, 3 reports from governmental institutions or research consortia, 3 reports or presentations from industry associations and/or consultancies, 1 company presentation, 1 PhD thesis and 1 Master's thesis. The publications originate from 13 different research groups, organisations or companies.

There are only five publications with an explicit aim to quantify the mass of a set of critical metals in passenger vehicles (Ministry of Environment Japan 2009, Alonso 2012, Cullbrand and Magnusson 2012, Du 2014, Widmer 2015), of which two are from the same study. In addition there are some reports focusing on steel and aluminium (Ducker Worldwide 2011, Ducker Worldwide 2012, European Aluminium Association 2013). The rest of the references contain scattered data on selected elements or components, mainly based on secondary sources.

The four studies that focus on critical metals content in passenger cars were compared in a meta-study by Du et al. (Du 2015). They all present results on the vehicle level, e.g. grams of Nd per vehicle (e-p). These numbers were calculated from data on the component level, either obtained by sampling and chemical analysis, or product information from the manufacturer. Two of the studies also provide comprehensive data on the component level (Ministry of Environment Japan 2009, Widmer 2015), while the remaining two provide data on the "subsystem" level or component group level (Alonso 2012, Cullbrand and Magnusson 2012). The most commonly studied elements are the rare earth elements La, Sm, Nd and Dy, which were included in all of the studies.

The 17 studies together provide data on 10 different vehicle keys, which mainly differ in power source and vehicle segment. The studies on critical metals cover only individual vehicle model years (2002, 2011, 2012) or a narrow range of years (2005-2008), while the studies on aluminium contain historical development of aluminium content as far back as 1979 and scenarios until 2020.

Table 2: Occurrence of CRM Parameters in Data-sources on Vehicles. Green: reference contains data on specified CRM parameter. Red: reference contains no data on specified CRM parameter.

Author - Date	e-m	e-c	e-p	m-c	m-p	c-c	c-p	p-p	p	c
Alonso, E., T. Wallington, A. Sherman, M. Everson et al. (2012)			x							
Cullbrand, K. and O. Magnusson, (2012)			x							
Du, X., R. Widmer, E. Restrepo and P. Wäger (2014)		x	x							
Ducker Worldwide, (2011)				x	x					
Ducker Worldwide, (2012)				x	x					
European Aluminium Association, (2013)					x					
Habib, K., H. Wenzel (2014)		x								
Habib, K., P. K. Schibye, A. P. Vestbo, O. Dall and H. Wenzel (2014)	x	x	x		x		x			x
Jody, B., E. Daniels (2007)		x			x					
Kummer, B., (2014)			x		x					
Labie, R., G. Willems, D. Nelen and K. Van Acker (2015)		x			x					x
Løvik, A. N., R. Modaresi and D. B. Müller (2014)		x			x					
Ministry of Environment Japan, (2009)		x	x							
Modaresi, R., D. B. Müller (2012)					x					

Sander, K., W. Kaerger, M. Groke, M. Bergamos and R. Kohlmeyer (2014)		x	x							
Widmer, R., X. Du, O. Haag, E. Restrepo and P. A. Wager (2015)		x	x							
Zepf, V., (2013)		x								x

The availability of composition data on CRMs in vehicles is low compared to the two other product groups. Although the studies cover different model years (2002, 2005-2008, 2012), it is difficult to analyse temporal development of CRM content, due to other differences in the characteristics of the vehicles studied and the small number of studies. All of the studies provide some composition data on subsystem or component level. However, comparison is impeded by inconsistent subdivision of vehicles into subsystems and components. Moreover, each study only investigated a subset of the vehicle components. To conclude, there are large data gaps on the composition of passenger vehicles, particularly for CRMs.

The literature search was mainly targeted at publications on critical and scarce metals. Within this set of elements the information presented is believed to reflect available data accurately. For bulk metals and hazardous substances there is more information available than presented here. It has not been decided whether a systematic search for this information is prioritised over a more in-depth search for scattered data on critical raw materials. In addition, there are known databases which contain a lot of potentially useful information, such as the International Material Data System (IMDS), which collects information about all materials used in automobiles directly from the manufacturers, or the International Dismantling Information System (IDIS) which contains information about car models relevant for depollution and dismantling. These databases are not publicly available and have not been included in the overview presented here.

3.3. Electrical and electronic equipment (EEE)

The data sources analysed regarding CRM content of EEE is presented in Table 3. In comparison with the other products flows, BATTs and vehicles, there is the highest number of sources available on the chemical composition of EEE. However, these are predominantly focused on the more obvious products like mobile phones and PCs and far less on other commonly used products like tools and luminaires. Much less information is available on some of the professional equipment and many individual small appliances like monitoring or medical equipment. Where batteries for instance can be regarded as a component with a limited set of chemical cells, EEE contains the whole range of possible components. In addition, some of the components undergo rapid development, like in the case of printed circuit boards with a high degree of miniaturisation over recent years. Moreover, for newer generation products generally very little information is available since it is very costly to dismantle and analyse chemical composition for the broad range of EEE products.

Information is primarily available from scientific journal articles and research or policy reports. With regard to journal articles, in some cases the origin and representativeness of the data is not always clearly specified. For the research and policy reports, data consolidation has taken place but the underlying steps and the distinction between original and 'reconstructed data' is often not clear nor specified. Roughly 25 sources contain original data on CRM parameters, around 20 compiled data and the same number counts for secondary information.

So-called full material declarations for EEE products are seldom publicly available, and rarely 'full'. Incomplete data for a significant amount of components in EEE makes its potential use less attractive compared to, for instance, the IMDS approach in the automotive sector.

Table 3: Occurrence of CRM Parameters in Data-sources on EEE. Green: reference contains data on specified CRM parameter. Red: reference contains no data on specified CRM parameter.

Author	Date	e-m	e-c	e-p	m-c	m-p	c-c	c-p	p-p	p	c
Bakas, I.	2014			x							
Bastein, T.	2014			x							
Binnemans, K.	2013		x								
Bollinger, L. A.	2010			x							
Böni, H.	2011										
Böni, H.	2015		x	x				x			
Brechbühler-Peskova, M.	2016		x	x							
Chancerel, P.	2013		x								
Chancerel, P.	2015			x							
Ciroth, A.	2011						x	x			x
Cucchiella, F.	2015										x
Department for Environment, Food and Rural Affairs	2012			x							
Eurostat	2016				x	x					
Fitzpatrick, C.	2015			x							
Habib, K.	2014		x			x					x
Habib, K.	2015				x		x				x
Habuer	2013			x		x		x			

Hoenderdaal, S.	2013		x								
Huisman, J	2008					x					
Kalmykova, Y.	2015							x		x	
Kasulaitis, B.V.	2015			x		x					
Labie, R.	2015		x			x					x
Magalini, F.	2015			x							
Marwede, M.	2013			x							
Miller, T.R.	2012			x							
Navazo, J. M. V.	2013			x							
Oguchi, M.	2011		x								
Oguchi, M.	2012		x		x						
Paginu, V.	2011					x					
Pannuzzo, B.	2014		x	x							
Polák, M.	2012			x							
Rademaker, J. H.	2013	x	x	x							
Rotter, V. S.	2013						x				
Rotter, V.S.	2013							x			x
Rotter, V.S.	2015		x	x						x	
Savvilotidou, V.	2014		x	x							
Schischke, K.	2014		x		x			x			
Sommer, P.	2015			x							
Sprecher, B.	2014					x					
Sun, Z.	2016		x								
Taghipour, H.	2014			x							
Ueberschaar, M.	2015	x	x	x							
Van Eygen, E	2016			x							
Wang, F.	2013									x	
Wang, F.	2014			x							
Wang, R.	2014		x			x					
Yamane, L.H.	2011		x								
Zeng, X.	2016			x							
Zepf, V.	2013		x								x

The availability of composition data for EEE is summarised in
. Among the reviewed references for EEE (121), 60 were found to contain relevant EEE CRM parameter data. The highest number of data points are found for laptops and tablets (25), followed by mobile phones (22) and desktop PCs (20). The lowest number of data points is available for lamps and many small equipment types (5-7 references). However, here most data does not fit the UNU key (see Deliverable 5.3, section 5.2), but rather the composition of the related collection category.

Not surprisingly, the highest number of sources cover the base metals and precious metals. For some more exotic elements like rhodium or ruthenium hardly any compositional information is identified. In the best case, only rough statistics can be found on their percentage use in EEE and for specific components, actual measurements are as scarce as the application of the element involved.

4. CONCLUSIONS AND OUTLOOK

4.1 General findings

Data on CRM parameters were identified in scientific literature and grey literature. No official, publicly available databases containing data on CRM parameters were identified. However, relevant databases that are not publicly available, such as the IMDS database of vehicle manufacturers and individual databases from compliance schemes with WEEE sampling and chemical analysis results, are known to contain further information on CRM content in products.

The general availability of CRM parameter data is moderate and highly dependent on the type of product, component and element. It can be concluded that in general the focus with regards to CRMs is on products and components containing a high mass fraction of CRMs, such as laptops and mobile phones. CRM data are usually available on the element level, while bulk materials data typically are on the material level (i.e. as alloys). The most commonly studied elements are aluminium, copper, iron, cobalt, neodymium and nickel. The least commonly studied elements are natural graphite, osmium and iridium.

Considering all (336) data sources currently included in the ProSUM bibliography (i.e. all data sources that have been identified in Deliverables 2.2, 3.1 and 4.1), Figure 3 gives an overview of the number of studies addressing the elemental composition of products and components with regard to the CRM in the scope of ProSUM.

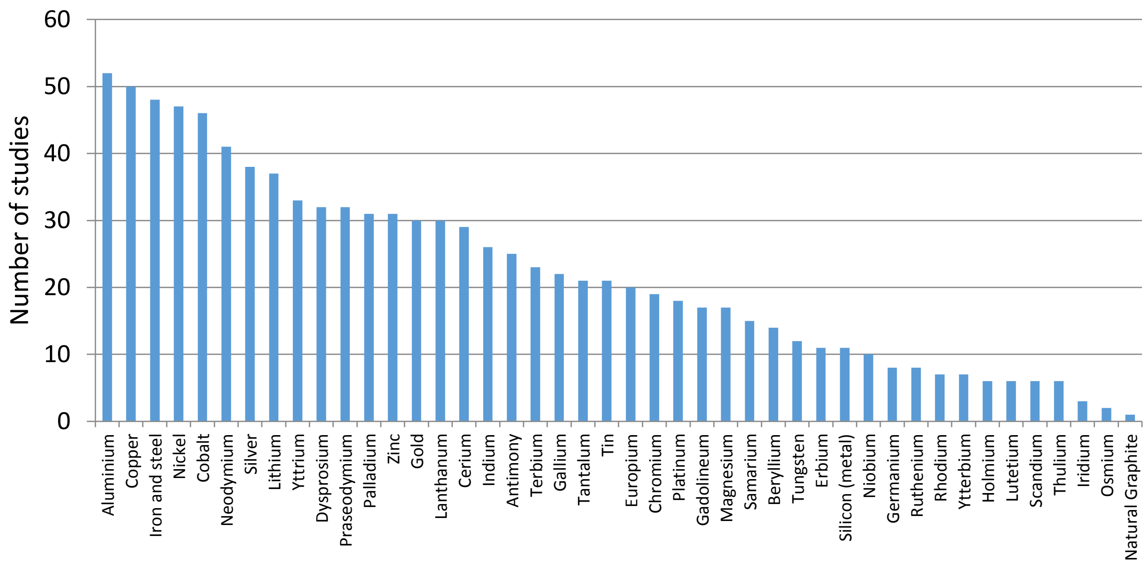

Figure 3: Number of studies included in the ProSUM bibliography addressing the CRMs within the ProSUM scope

4.2 Specific findings

The data availability relative to the defined ProSUM code lists can be characterised as high for batteries, medium for EEE and low to medium for vehicles.

For batteries, most of the defined keys are well covered with composition data. However, speciality products as well as supplementary components (e.g. printed circuit boards for battery management systems for more advanced types of batteries) are generally left out-of-scope in the data-sources reviewed.

For EEE, there are a large number of studies on the composition of a few specific keys, especially mobile phones, personal computers and TVs, but most of defined keys have very little data available. An overview is shown below by EEE product category and the number of data sources describing the composition of products per category.

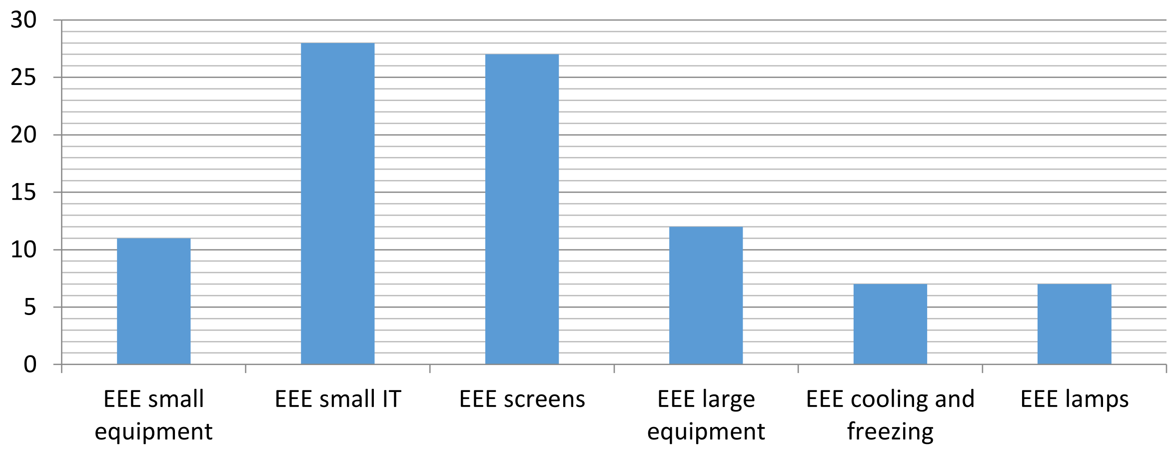

Figure 4: Number of data sources describing compositional information for the EEE product categories

For vehicles, data is available on 10 of the defined keys, for example vehicles with mass between 1000 and 1250 kg, hybrid powertrain and a cylinder capacity of 1400-1999 cm³. Although there are many keys specified for which no data exists, some important variations are covered, such as the difference between conventional, hybrid and electric cars.

4.3 Next steps

The data screening in Task 2.1.1 was conducted using an EndNote library (the ProSUM bibliography), currently containing 336 references, of which 121 contain data on CRM parameters. The ProSUM bibliography is specifically set-up to be able to categorise, filter and manage the continuously growing knowledge base behind the first Urban Mine Knowledge Data Platform in Europe. In the continuation of the work in the ProSUM project, the ProSUM bibliography will be continuously expanded with new references as they become available, as part of Tasks 2.1.2, 2.1.3 and 2.2 and all other work packages that use data-sources, databases and other external sources for assessing the CRM content in products and components, CRM stocks & flows, and waste fractions. Furthermore, the CRM parameter data identified in Task 2.1.1 will be extracted and recorded in an Excel file developed as part of Task 2.2. Three important issues were identified that need to be addressed in the continuation of the project: lack of CRM parameter data, availability of data not within the current scope of code lists, and differences in terminology in literature and in ProSUM.

Lack of CRM parameter data

The lack of CRM parameter data for many product keys and components is the most important issue to address in the continuation of this work. There are at least three possible ways of dealing with this: i) continued search for data; ii) estimation based on existing data for other product keys and components; or iii) narrowing down the scope, for example by aggregating keys to a higher level. In general, it is expected (based on the experience gained during this ProSUM task) that a combination of the three will be required.

i) Continued search for data

As an example, the data gap for advanced batteries (the lack of information about the electronics parts of batteries) could be compensated for by using the more complete data presented for environmental studies (such as the Bill of Materials use for LCA). The same mechanism for data-mining could be applied for the other product categories. However, for LCA studies there is a common “cut-off” rule which generally dictates the exclusion of materials lower than e.g. 1 mass% of the total weight, because otherwise the study simply takes too long, and the assumption is that these materials will not have a significant impact on the final result of the environmental study. This generally results in summing up the CRMs in LCAs as “other”, which does not aid our data search. However, the data presented in such studies on material quantities is often of a high quality.

Another field for continued search for data could be patent applications, since these generally require a detailed description of the proposed solutions.

Additionally it is proposed to present the current overview of available data to key experts outside the ProSUM consortium in order to discuss the completeness of the data sources and identify further valuable publications, databases or other information for quantifying the CRM content of products and components for the ProSUM project. The interviews will take place in Spring 2016.

For bulk metals, plastics and hazardous substances in vehicles, batteries and EEE there is (much) more information available than presented here, since the data review was aimed at data concerning CRMs. Additional scientific publications and other data sources on these materials will be collected and described when they are encountered.

While publicly available data on CRM parameters are scarce, there are several known non-public databases containing relevant information, such as the IMDS and IDIS. An option would be to use such data in the ProSUM project by signing non-disclosure agreements with the relevant parties. This will require that the data are aggregated or used in calculations in such ways that the raw data cannot be traced back through the Urban Mine Knowledge Data Platform. The ProSUM bibliography allows the references to be tagged as confidential when described, and this information must be retained through the further use of the data. In a first step, the possibility of using such confidential data will be explored with selected companies or organizations holding data of particular interest.

ii) Estimation based on existing data

If data cannot be obtained for components or products that cannot be excluded from the scope, a possible solution is to estimate CRM parameters based on data for other products and components. In general this can be achieved by using either a direct proxy (e.g assuming the mass fraction of gold in a tablet computer equals the mass fraction of gold in a smartphone), or a model (e.g. mass fraction of gold in tablet computers equals half of that in smartphones). The "hot-spot" approach discussed in the next point might also be viewed as a kind of estimation model, which in addition narrows down the scope with respect to components. Regardless of the approach, such estimation introduces additional uncertainties. Clear criteria for the acceptability of such estimates will have to be developed within Task 2.2.

iii) Narrowing down the scope

For products and components where no data is available and no acceptable estimates can be made based on other products and components, the only option might be to narrow down the scope. This can be done either by excluding a product or component altogether, or by quantifying its CRM content at a higher level. For example, if data is only available for a group of components together, this component group might replace the set of components comprising it, thus reducing the number of components being covered.

Because of the large number of components, especially in vehicles and EEE, a "hot-spot" approach is an attractive option for arriving at product-level composition. This involves selecting a subset of components and using composition data for this subset of components to estimate the CRM content in the entire product (see e.g. Widmer et al. 2015). The underlying assumption is that this subset contains the majority of CRM mass in the product. The hot-spot approach will be tested in the immediate continuation of the project, with identification of the hot-spots as the first step.

Availability of data on products and components not covered by ProSUM code lists

The second important issue to deal with is the availability and relevance of data on products or components which are currently not covered by the ProSUM code lists. This could be addressed by expanding the code lists, but it is important to make sure that such expansion also makes sense considering the availability of data on stocks and flows. Related to this, some data sources were identified which present CRM data, typically element mass fraction, in a product category that is wider than the highest level product keys in ProSUM. These data could often be described by introducing a higher level, waste (w), in the CRM parameter list presented in Section 2 of this report, and thus generating a new set of CRM parameters labels*: e-w, m-w, c-w, p-w*, analogous to the ones already defined here. The introduction of these parameters will be coordinated with WP4, as it concerns the characterisation of waste streams.

Some types of batteries, EEE and vehicles have not been taken in to account in the current scope due to a known lack of data on stocks and flows of these products, which prevents calculation of the total mass of CRMs contained in them. Of course one should eventually include products and components which are currently out of scope, but combining the lack of data with the assumption that these “speciality products” are likely to represent a very small percentage of their respective markets, it can be concluded that, for now, no immediate actions are required.

Differences in terminology in literature and ProSUM

A third important issue to deal with is the inconsistency between terminology used in literature and the code lists defined within ProSUM. It is sometimes difficult, especially on the material and component level, to accurately describe the references, for example because measurements have been done on a component defined differently than in the ProSUM components list. The issue of data being incompatible with ProSUM code lists is especially important for the component level of vehicles. A harmonisation of such data can only be achieved at the level of detail available for the least detailed data, for example, by aggregating components to the subsystem or product level. For vehicle data, harmonisation is perhaps only possible on the product level. Focusing on the product level is consistent with the hot-spot approach, in the sense that no attempt is made to quantify the CRM content for every component in the product.

Product key code lists do function sufficiently. For example, for EEE the UNU code-list is highly detailed, especially in combination with their sub and sub-sub keys, and is already applied more widely also outside the ProSUM consortium, for instance in the common methodology study for the European Commission regarding market input and WEEE generation (Magalini et al, 2016).

In the continuation of the project, the CRM parameter data will eventually be combined with stocks and flows data to arrive at estimates for the total mass flows of CRMs in stocks and flows. This process will require a combined effort between WP2, WP3 and WP4 to harmonise the use of code lists where modifications are required (addition, exclusion or aggregation of codes).

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6. ANNEX 1 – MANUAL FOR ENTERING DATA SOURCES INTO THE PROSUM BIBLIOGRAPHY

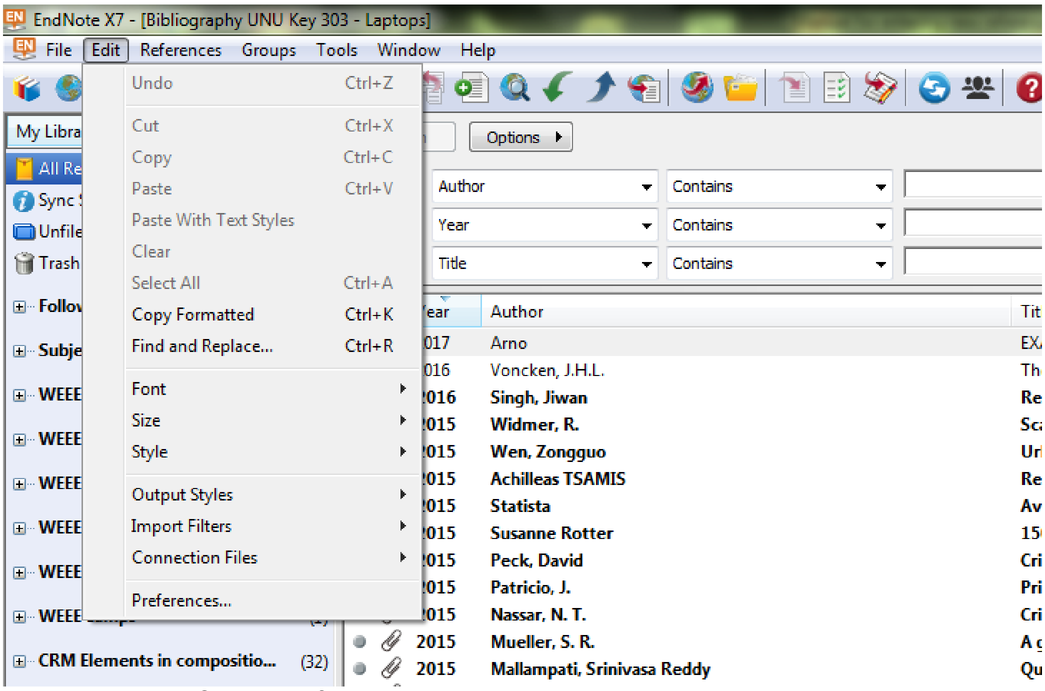
1. Open EndNote
2. Open The Shared Library (only available for ProSUM members through invitation)

6.1 Preparation

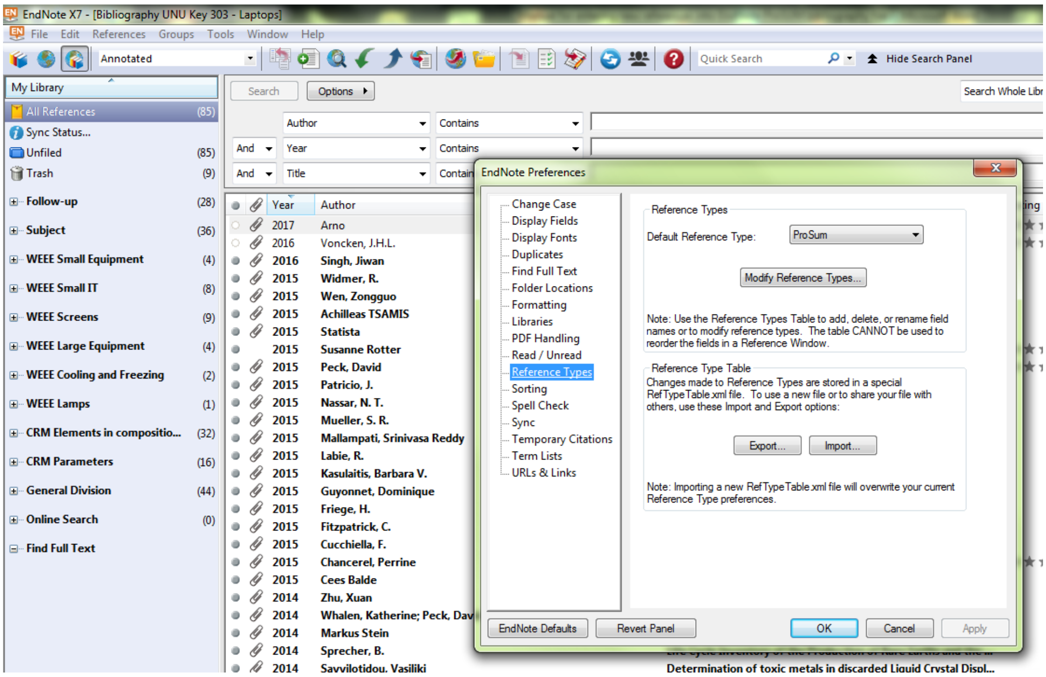
3. Import and install latest version of the "ProSUM" Reference type table, available in this folder on Dropbox:

[Dropbox\ProSUM\Bibliography - ALL WP's\Bibliography WEEE UNU TUD\Bibliography UNU Key 303 - Laptops\Reference Type Table for ProSUM Bibliography\]()

   a. Go to and click the tab "Edit"



   b. Click "Preferences"
   c. In the left pane of the preferences menu, click "Reference Types"



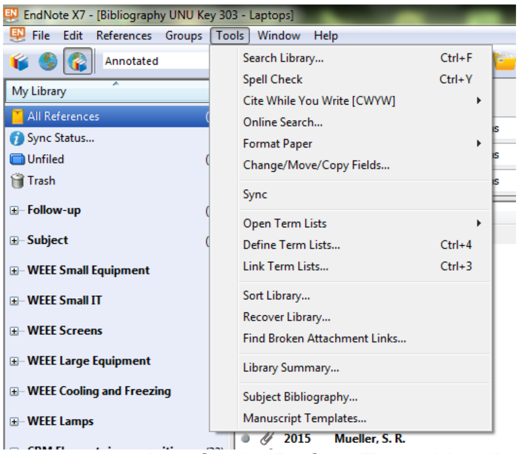
d. In the right pane, click the button “Import…”

e. Navigate to the latest Reference Type table in the folder on dropbox (see link above) and click “Open”.

4. Import <u>all</u> Term-lists from dropbox into the EndNote library. Unfortunately, this is quite a tedious task, but should not take more than 30 mins, and you only have to do it once. All relevant term-lists can be found in this folder on Dropbox:

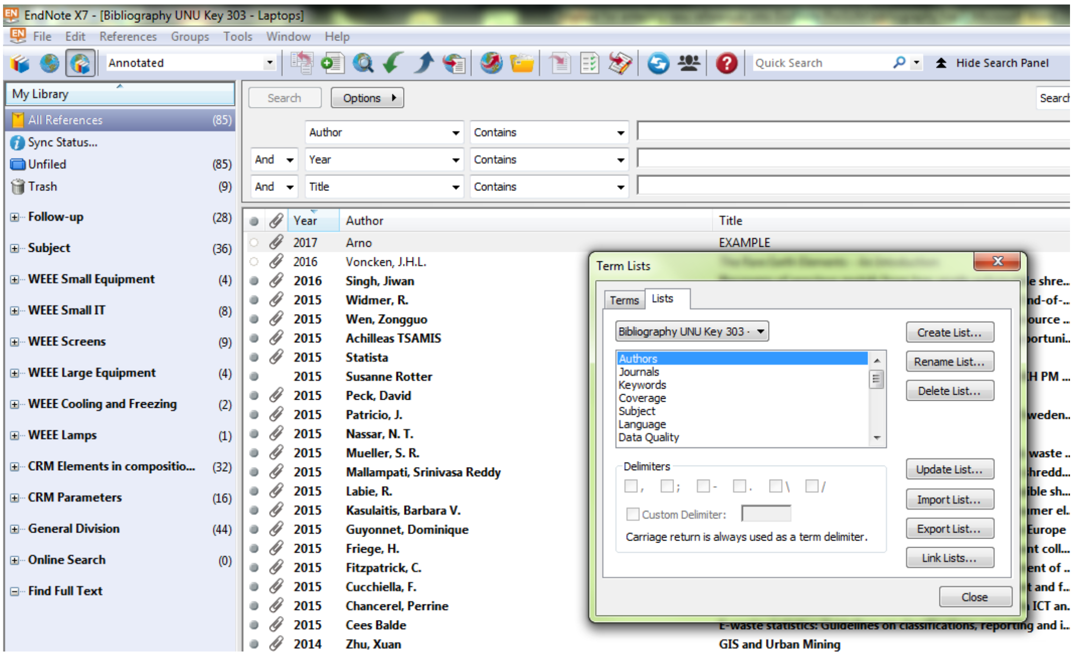
[Dropbox\ProSUM\Bibliography - ALL WP's\Bibliography WEEE UNU TUD\Bibliography UNU Key 303 - Laptops\Term lists for bibliography\]()

a. Go to and click the tab “Tools”

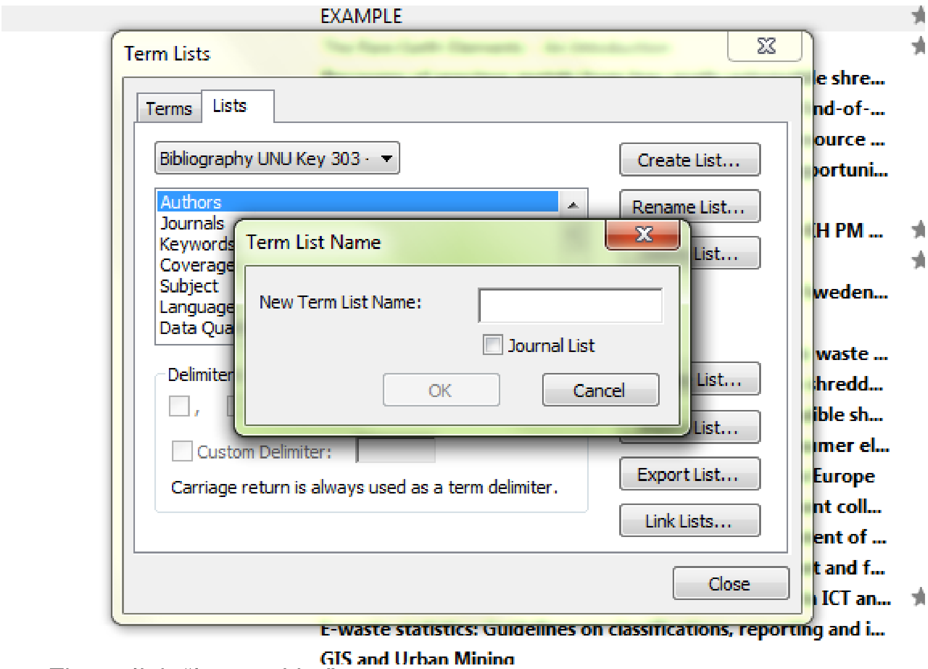


b. Click “Define Term Lists”

c. Click “Create List” (If you want, you can delete the lists “Authors”, “Journals” and “Keywords”… we won’t be using these)

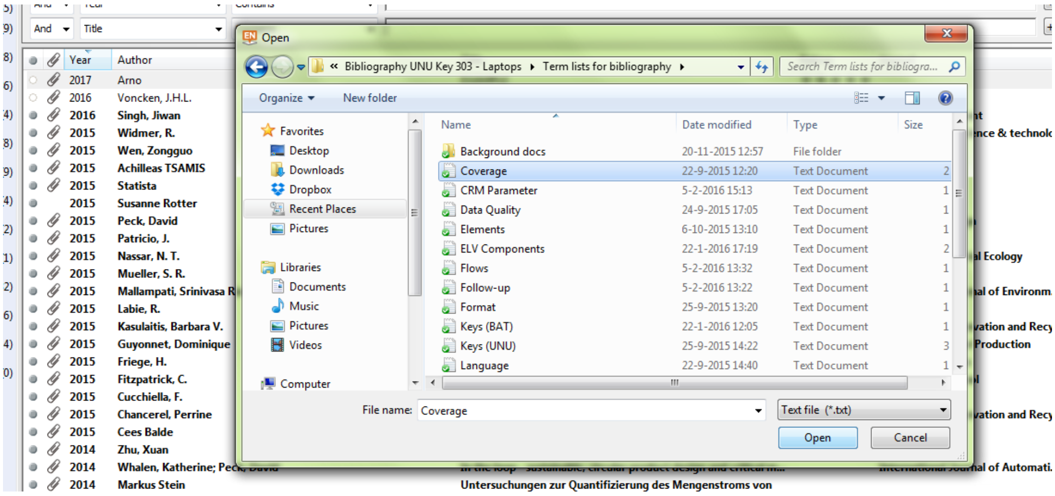


d. Enter the name of the Term List you want to import (see the above-mentioned folder on Dropbox) and click "OK"



e. Then click "Import List"

f. Navigate to the Term List folder on Dropbox and select the corresponding Term List with the name you entered in step d.



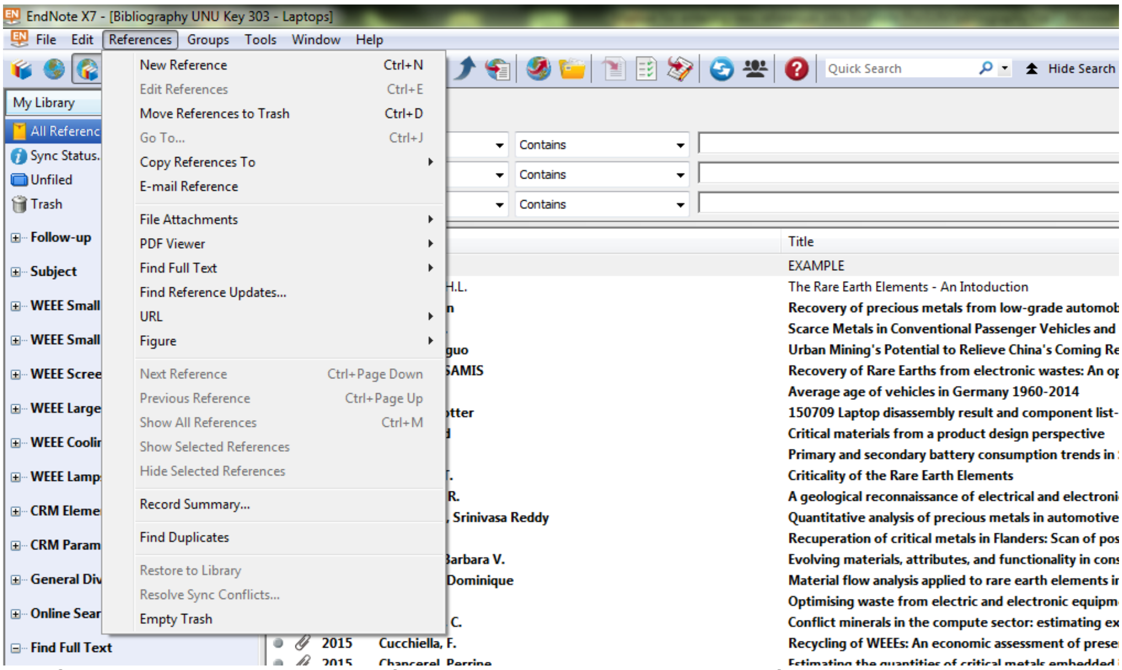
g. Click “Open”

h. You should get a notification stating that “ x terms have been imported successfully”

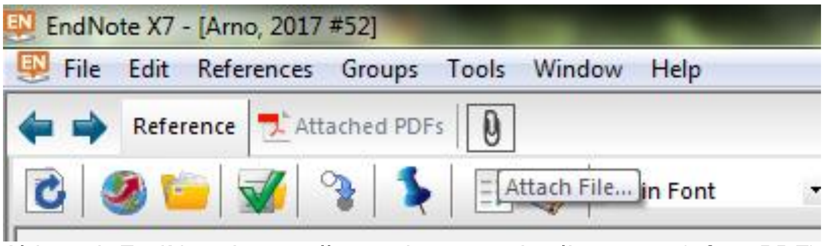
i. <u>Repeat steps c-h until you have imported all term lists.</u>

6.2 Input of references and/or data-sources

5. Input your references/data-sources into the bibliography

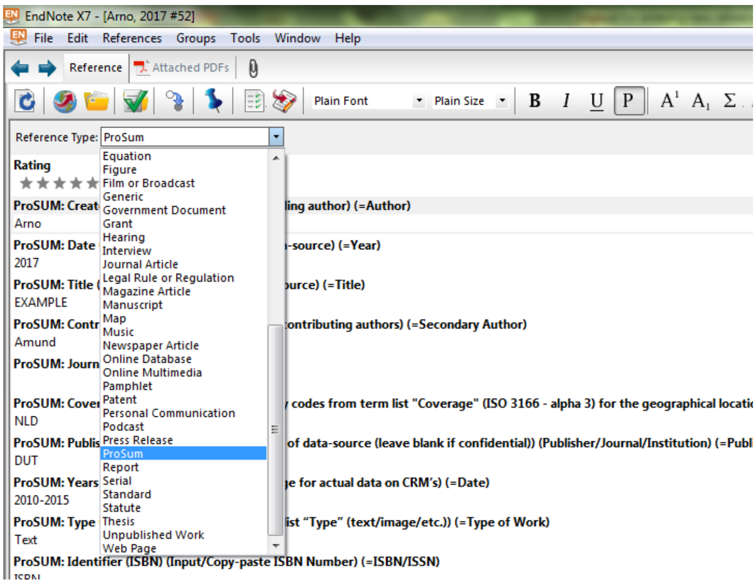


6. Double-click the new reference in the overview ("All References")
7. Attach the PDF of the reference/data-source to the new reference.



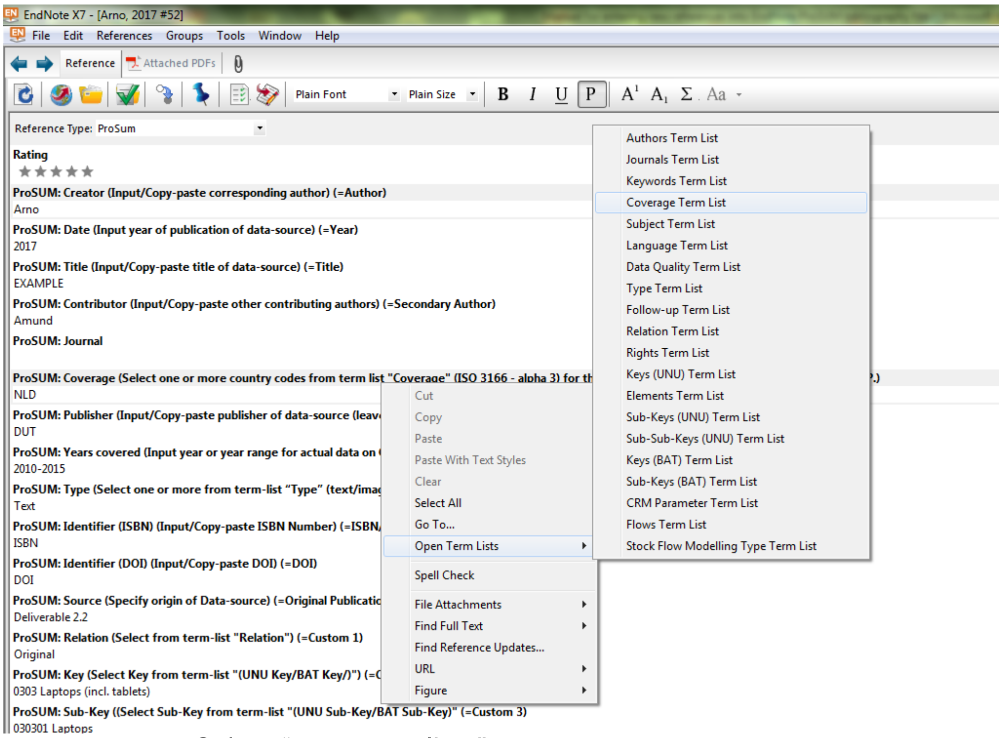
Although EndNote is usually used to organize literature (often PDF), other files such as excel, word, access, etc. etc. can be added as well: Click "Attach File" (i.e. the paperclip icon), and select the file you want to add to the bibliography entry.

8. Select reference type "ProSUM"



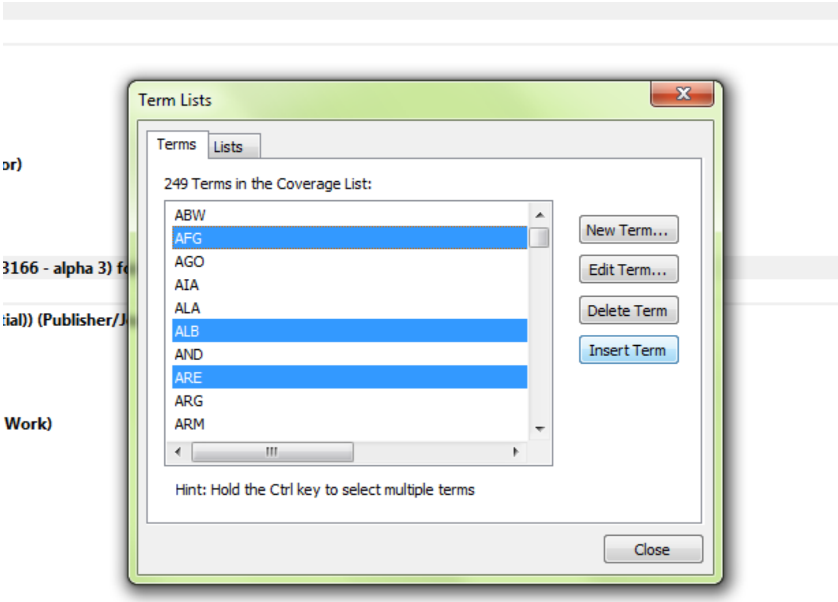
The bibliography contains a reference named “example”. This can be used to check how the meta-data should be described.

9. Input all meta-data fields as instructed per field. Some are to be put in manually (simply type in the meta-data descriptor field), but most are to be filled in using a “term list”:
    a. Select the meta-data descriptor field you are completing
    b. Right-click on the meta-data descriptor field



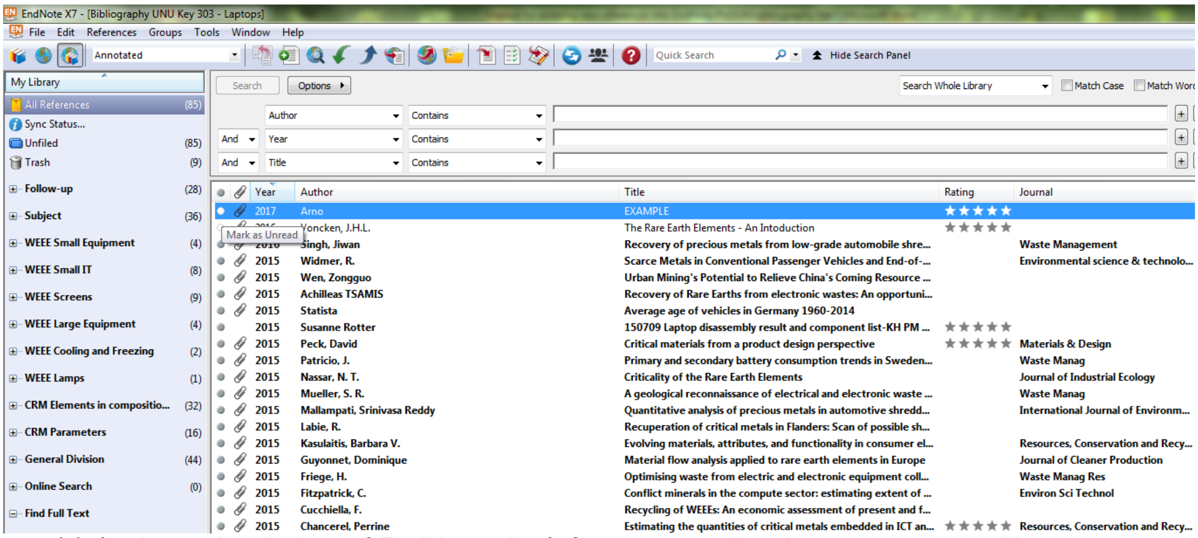
    c. Select “open term lists”
    d. Select the relevant term list for the specific meta-data descriptor
    e. Select all relevant inputs from the term list for that meta-data descriptor (Hold down “CTRL” to select multiple terms)

    f. Click “insert term”



The selected terms appear in the field on which you first right-clicked. Please make sure they ended up in the right field. It is important to use the term-lists when indicated for that meta-data descriptor field.

10. Complete all relevant fields for the data source. If the data-source connects better to another team-members' responsibilities and/or expertise, indicate the person(s) in the field "follow-up" and <u>**mark the data source as "Unread"**</u>: An entry is "unread" when it is marked in **bold** text. You can use the "ball" to the left of each entry to toggle between Read/Unread.



11. In the main window of EndNote, the left-pane contains the smart groups. Here you can see which documents you are supposed to follow-up.
12. If you have completed the meta-data descriptors for the data-source, <u>only then</u> mark the data-source as "Read". An entry is "Read" when it is marked in plain text.

6.3 Smart groups

Optional: You can create smart-groups to filter the bibliography references according to your own needs. Many smart groups have already been created, but they might not suit your specific needs. If you want to create one, go to the main overview in EndNote ("All References") and right-click in the left pane. Select "create new smart group" and add search parameters to that group. The field names which you can search/filter do not correspond to the ProSUM meta-data fields, therefore these are indicated between brackets in the names of each meta-data descriptor field.

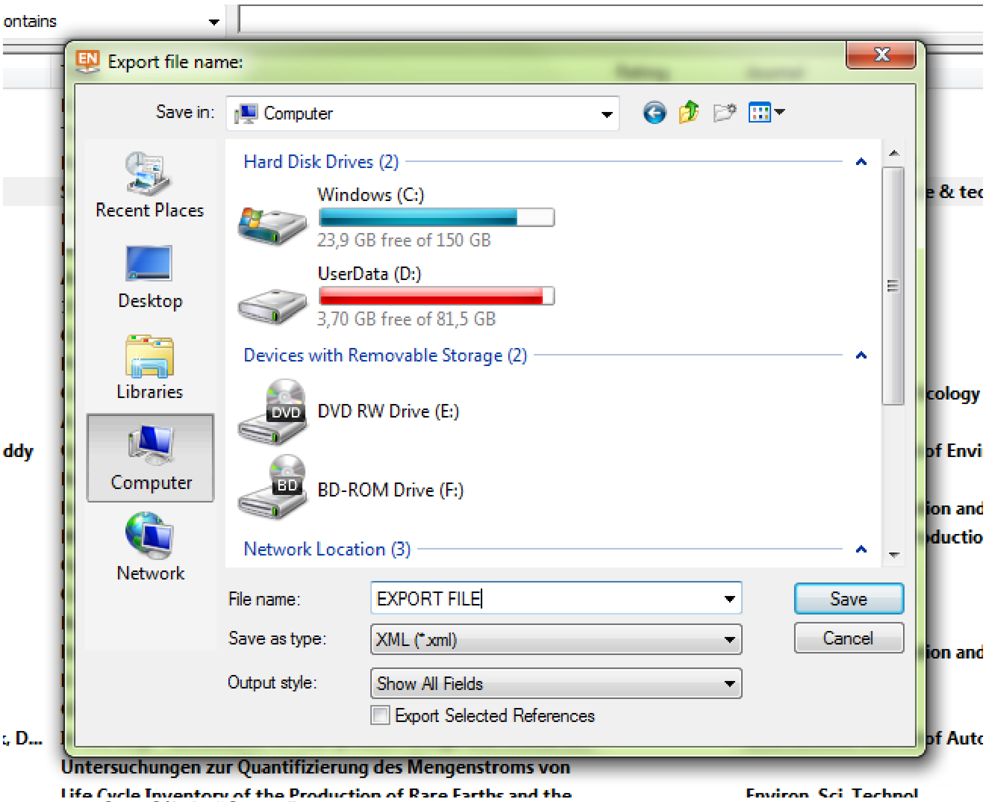
6.4 Custom search

You can drop down the Search Panel, where you can do a quick search through the entries in the bibliography. You can either search all fields for a specific meta-data entry, or a specific field. Again, the field names which you can search/filter do not correspond to the ProSUM meta-data fields, therefore these are indicated between brackets in the names of each meta-data descriptor field.

6.5 Export to XML file

The DUT is asked whether export of the bibliography to excel is possible. It is:

1. Go to the tab “File” and click “Export”
2. Name the file according to your needs
3. Select from the drop-down menu “XML” for “Save as Type”
4. Select from the drop-down menu “Show all fields” for “Output style”
5. Uncheck “Export selected references” (unless you only want to export selected references of course)



6. Click “Save”
7. Now the file can be opened as an XML table in Excel

7. ANNEX 2 – OVERVIEW OF SCANNED DATA SOURCES ON CRM PARAMETERS

See attached Excel file < Annex 2 – CRM Parameters in Batteries, Vehicles and EEE data sources >