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Technical Guideline
Tools for harmonization of data collection on Batteries

Related to Deliverable 2.3 and 4.1

Project	Optimizing quality of information in RAw MAterial data collection across Europe - ORAMA
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The ORAMA project is a H2020 project and aims to improve and demonstrate the interoperability of raw materials datasets between national and international systems. Furthermore, it addresses specific challenges related to data availability, geographical coverage, accessibility, standardisation, harmonisation, interoperability, quality, and thematic coverage in Member States.

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This document provides guidance in procedure to harmonize different type of datasets for Waste Electric and Electronic Equipment (WEEE) /PV. The guidelines is a result of a thorough analysis and data gap identification on data reporting methods and the implementation of prioritized case studies from WP2.

This document will be presented on the ORAMA Workshop in the JRC (ISPRA), 12-14 of June 2019, in cooperation between the ORAMA Partners and JRC Team dealing with the development of the Raw Material Information System.

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Acronyms

BEV: Battery Electric Vehicle

BATT: Batteries

CRM: Critical Raw Materials

DB: Database

ELV: End of Life Vehicles

EC: European Commission

EOL: End of Life

HEV: Hybrid Electric Vehicle

KF: Key Figures

MFA: Material Flow Analyses

MS: Member States

NiCd: Nickel-cadmium

NiMH: Nickel-metal-hydride

PHEV: Plug-in Hybrid Electric vehicle

POM: placed on market

ProSUM: H2020 project – Prospecting Secondary raw materials in the Urban mine and Mining waste

RMIS: Raw Materials Information System

REEs: Rare Earth Elements

SRM: Secondary Raw Materials

UMP (previously known as: EU-UMKDP): Platform for prospecting secondary raw materials in the Urban mine and Mining wastes, ProSUM.

WP: Work package

xEV: Electric vehicles including BEV, HEV and PHEV

Glossary

Code list

A class representing a type of controlled vocabulary containing a finite set of codes, where each code value refers to a meaning or concept that is distinct from meanings associated to other codes in the code list. The list can be extended if necessary under certain conditions.

Collection

The gathering of waste, including the preliminary sorting and preliminary storage of waste for the purposes of transport to a waste treatment facility (Directive 2008/98/EC).

Disposal

Any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy.

Harvesting database

The (Central) Harvesting Database (DB) is 'connected' to the data providers and receives their data through Web Feature Services (WFS). The structure of this DB exactly reflects the INSPIRE Mineral Resources (MR) data model. Another role of this DB is to check the quality of data and their format. For this project, the Harvesting DB is hosted by the Geological Survey of Slovenia (GeoZS) and connected to the Diffusion DB using SQL scripts.

Non-compliant

Commonly known as complementary or unreported treatment refers to products being treated or disposed and not reported nor declared to National or Member States registers and to Eurostat.

Registered (reported) Flows/Collection

The quantities of WEEE reported to Member State registers and Eurostat WEEE database (Wielenga et al., 2011).

Unreported flows

The unreported flows are declared to Member State authorities under different reporting regimes.

1 Introduction

Currently, there is a need to optimize, harmonize and further develop the data collection methods for material flows across Europe in order to improve the data quality and promote traceability of potential Secondary Raw Materials (SRM) in the urban mine (D2.1 and D2.2). As a result, the project supports the European Union Raw Materials Knowledge Base (EURMKB) which will feed the European Commission (EC) Joint Research Centre’s (JRC) Raw Materials Information System (RMIS). ORAMA´s main goal is to provide tools to harmonize Raw Material (RM) data collection by selecting and providing recommendations from a detailed inventory and data gap analysis for potential improvement of datasets resulting from prioritized actions (D2.2) and conducted case studies for the different waste groups (D2.3).

In doing so, produce a technical guideline describing best practices related to the provisioning of data for SRM. This guideline will enable new data providers to set up the necessary mechanisms for establishing interoperable services with high-quality data but will also provide guidance for existing data providers on how to improve the quality of the datasets already provided. This technical guideline fed into training material that will be used in a workshop and webinars (Task 4.2).

Whereas this documents contains information and tools for Batteries in special, the Deliverables 2.2, 2.3, 4.1, and 4.2 of the ORAMA project also contain results, recommendations, case studies, and tools for WEEE, ELV and MIN WASTE.

1.1 Overall Aim

The overall aim of the Technical Guideline is to provide a credible and practical harmonization methodology on how to improve data collection methods for data providers, governments, policy makers and other interested stakeholders in Europe. The Technical Guidelines principles is expected to support the improvement of the data knowledge base across Member States.

1.2 Target audience

The Guideline is aimed to benefit and improve reporting practices across Member States, National registries, Statistical Institutes, data providers (which can be public authorities, industries and recyclers) and data collection procedures from the providers that are enforced. It is envisaged that there will be many beneficiaries from the improved practices resulting from the implementation of this guideline.

Furthermore, it aims to primarily benefit the European knowledge base of SRMs and benefit value chains stakeholders by providing the significant and relevant information with good data quality.

1.3 Outline

The following bullet points outline the structure of this report:

- Section 1.0 Brief introduction of the guideline; overview of the scope, target audience, aim and future application of this guideline.
- Section 2.0 Description of the importance of a proper systematization and harmonisation and its current status in Europe for Batteries.

- Section 3.0 Results of the ORAMA´s project inventory and data gap analysis done in D2.1 and D2.2, a prioritization of recommendations and actions to improve reporting of Batteries. In addition this section aims to provide a detailed description of other Tools developed in D2.3 from the case studies for Batteries in the ORAMA project.
- Section 4.0 Batteries case study.
- Section 5.0 References
- Section 6.0 Annex
    - Annex 1 Decision Tree for determination of battery chemistry used in xEV
    - Annex 2 Detailed Overview of xEV manufacturers, models and battery information
    - Annex 3 Overview of Existing data sources and needs for data for the flows and stocks of batteries from electric vehicles

2 Importance of systematization and harmonisation of data of Batteries, current status

2.1 Legal frame and relevance of reporting

Eurostat provides data on the sales of portable batteries and accumulators as“Products placed on the market” (POM) in tonnes. The Eurostat data addresses only portable batteries and does not differentiate between different chemistries and applications. The data inventory in D2.2 showed that Eurostat publishes data with a very low level of detail, which is not designed nor suitable to describe material content nor allowing a sophisticated quantification of material flows.

Each Member State (MS) has an own type of data collection and verification system in place. Even though Eurostat provides MS with a set of guidance documents in an effort to assist them on their battery data reporting (see also ORAMA Deliverable D2.1) on the methods used, the guidance documents still leave much room for different interpretations of the reporting requirements. This might be one reason for the lack of harmonization and results in inconsistencies of reporting between MS.

Data are not yet available on the collection of waste batteries from electric vehicles which consist of Hybrids (HEVs), Plug-in Hybrids (PHEVs) and battery electric vehicles (BEVs). So far, the collection and reporting of these data are not required by the legislations on batteries and vehicles, as batteries of electric vehicles (xEVs) are classified as industrial batteries. This may change with the implementation of the new Batteries Directive, which is currently under revision.

Batteries represent an interesting product group for proposing reporting harmonization due to their content of CRMs and their increasing market extension especially looking at lithium-based rechargeable batteries in electric vehicles. The trend towards electrified vehicles is expected to provide the largest share of the demand for Li-ion batteries in the next years. However, the compositions of Li-ion batteries vary considerably over time regarding CRM content and reliable information on market numbers are of high strategic importance not only to policy makers but also industry and recyclers. After the first use in electric vehicles, batteries may have a remaining capacity of up to 80% which qualifies them for a second life option in for instance energy storage applications (Bobba et al., 2019). The relevance of reliable data for CRMs from xEV batteries is likely to increase even more with second life scenarios in mind on one hand and improving durability of newer version on the other hand.

NiMH batteries which are among other applications found in electric vehicles and contain rare earth metals (REEs) which are also of high strategic importance for the EU. Current reporting obligations are lagging behind to give reliable information on CRMs flows and expected waste generation and need to be improved to overcome uncertainties in the estimates of the amounts of secondary raw materials. In order to receive information on the types of batteries used in electric vehicles currently three independent sources of data must be combined to get this information: the number of electric vehicles put on the market, the types and weight of batteries used in the electric vehicles and their lifespans. In order to conduct valid estimations on the magnitude of SRM inherent in the xEV battery system, data collection along the intermediate steps of the xEV value chain are crucial. Yet, little knowledge is found on this part of the value chain, also due to a lack of reporting obligations.

2.2 Differences in scope and data collection that require harmonisation

Reporting obligations concerning batteries are regulated by the Battery Directive (2006/66/EC). The Directive does not provide legally binding requirements on the data collection methods, for instance on the level of detail in the reported data to the EC, nor on the structure of the methodological reports that must be submitted.

Member States collect and publish their data on batteries placed on the market and collected very differently and the level of details of the reporting also varies significantly (for more details see D2.2.). The reporting obligation under the current directive 2006/66/EC distinguish only between 3 types of portable batteries: LeadAcid, NiCd and other batteries. The distinction between primary and secondary batteries is however important since most of the CRMs such as cobalt can be found in secondary batteries. The same is true for the chemical types. Providing information on the different chemical types of batteries will give a good indication on the CRMs embedded. This information is not only valuable to potential recyclers but also to other stakeholders like policy makers or in the case of xEV batteries actors in the second-use value chain for repair and remanufacturing purposes.

Consequently, the data reporting practices and methods of EU Member States reveal significant inconsistencies which leads to the assumption that the data reporting on the European level could be optimized towards a more reliable and harmonized information base on the flow of CRMs from batteries. Changing the level of detail in the data reporting requirements is crucial for the assessment of the CRM flows in the European urban mine. Thus, updating for instance current battery classifications with more detailed battery groups and subgroups is one important aspect proposed in this guideline.

Furthermore, the current Battery Directive focuses its legal requirements only on reporting of end of life batteries. Incentives to extend the lifetime of the high-performance batteries from electric vehicles for instance into different applications are missing in the current directive but might could find consideration as part of the current revision. Information on the applicability of second-life scenarios for certain battery applications stresses the need for a systemic overview even more. Improving the knowledge base of CRMs stock and flows includes taking into account the different actors and steps involved in the value chain of xEV batteries where new reporting obligations could help to close information gaps.

3 Prioritised recommendations and actions to improve reporting of Batteries

In this Section a comprehensive summary of existing recommendations regarding data collection methods across Member States identified in D2.2 are made.

3.1 *Prioritised recommendations for Batteries from the ORAMA project*

From a list of recommendations compiled in ORAMA Deliverable 2.2, four prioritised actions (1-4) have been selected for this guideline. To estimate the CRM flows, data with a level of detail distinguishing the different electrochemical battery systems is needed. The recommendations below are an effort to work against the still existing knowledge gaps in the battery value chain.

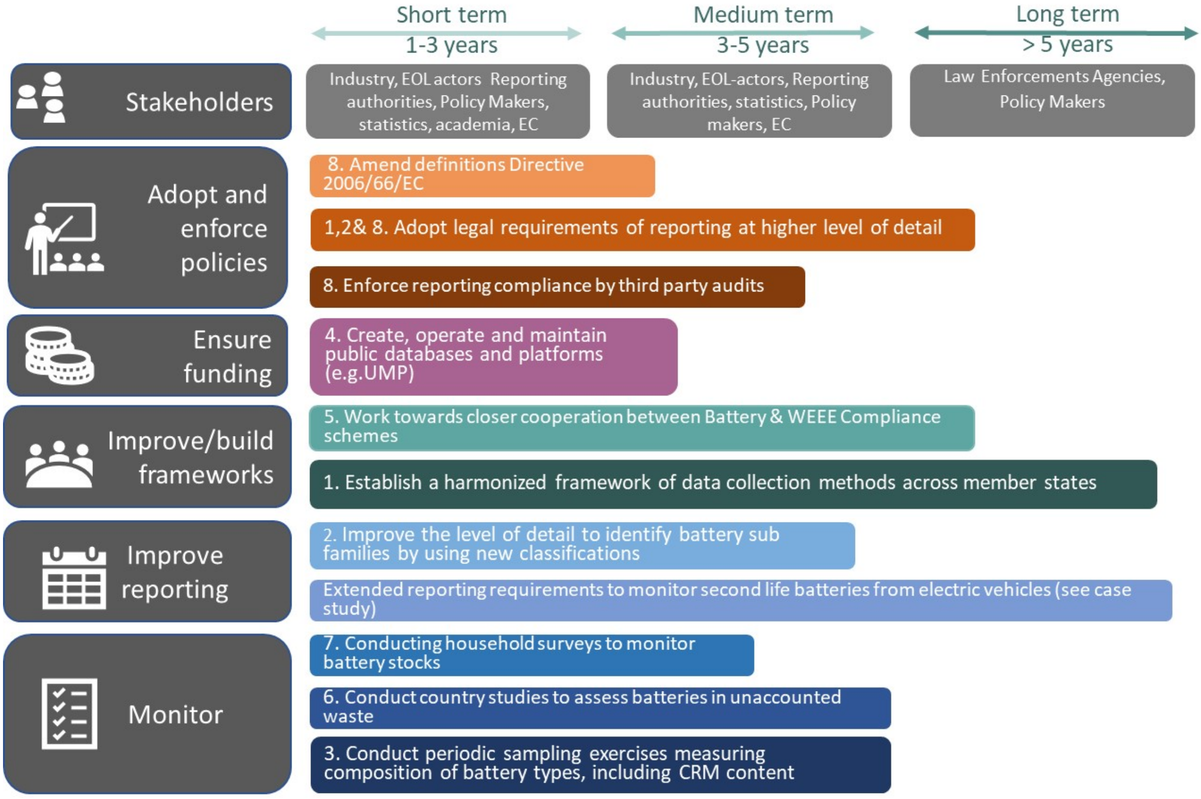

Figure 1 Prioritized recommendations for battery reporting

Figure 1 provides an overview of a wide range of recommendations to improve the reporting and data collection procedures for batteries. The first recommendation is very much in line with the overall goal of the ORAMA project to work towards a harmonized framework of data collection methods across European member states. As stated in the directive, sales information on chemistry types is voluntary data and is thereby not enforced by the EC. However, this information is crucial and should be made public to enable other stakeholders to collect information on CRMs flows from batteries. The methodological reports accompanying the reported data could give a good indication on how national data has been collected however it is not mandatory and thus the method of how certain countries perform their data collection is in transparent. A framework to get all actors on the same level and possibly assist authorities in their future reporting practices is a key recommendation. Regular meetings between reporting authorities, standardized training documents, classifications on e.g. batteries or expert workshops organized by the EC are a few suggestions to trigger communication and better interchange between relevant actors. Nevertheless, stricter formulations or reporting obligations could still be needed in the future to improve harmonization.

The second recommendation is an integral part of building a European harmonization framework described above and deals with a more technical classification system to agree on common classifications to better quantify the amount of CRMs in Europe. Chapter 4.2.2 shows a proposed Codelist (keys and sub-keys) to better classify batteries as developed by the ProSUM project.

Information on battery composition (on element level including CRMs) is hardly available also because battery manufacturers are reluctant to provide this information due to confidentiality issues. Nonetheless reliable information for instance on how battery compositions change over time is important to estimate future resource consumption scenarios. Public funding for maintaining up-to date aggregated data, for instance the information provided by the Urban Mine Knowledge Platform[1] on battery composition should be established. Improving the knowledge base of CRMs flows in Europe with up-to- date composition data can also enable the EC and national authorities to perform a check of the mass balances of strategic metals in the future.

The 4th recommendation deals with creating and maintaining databases and platforms with available data on materials contained in stocks and flows of batteries. This can be achieved by already existing platform such as the UMP and would reduce the amount of effort needed to be established. Maintenance of future battery data will particularly gain importance with the topic of second use of electric vehicle batteries for energy storage application and should be collected in a centralized platform on the stock and flows of CRMs.

Table 1 Summary of prioritized recommendations for batteries

Action	**Stakeholders Involved**	**Time Frame**	**Priority**	**Feasibility**
1 Establish a harmonized framework (interpretation of definitions, classifications, methods, documentation) for the data collection of across Member States.	European Commission, National authorities and Eurostat.	Medium term	High	This can be implemented via dialogue between the Member States and having a low to medium amount of human and financial resources.
2 Development of classification systems that would allow all Member States to categorise: 1. the electrochemical battery (sub-)systems 2. the applications 3. the stocks and flows of batteries	Researchers, European Commission, National authorities, compliance schemes, producers, recyclers.	Medium term	High	This can be implemented with dialogue between the Member States and having the medium amount of human and financial resources available. The feasibility of this action will depend on the agreement on classifications
3 Promote the declaration of battery composition to competent organisation or	Researchers, European Commission,	Long term	High	Requires agreement on confidentiality issues and level of aggregation enabling the

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[1] http://www.urbanmineplatform.eu/homepage

authority, improve the composition data to better cover trace and critical elements and battery electronics, and to understand changes over time	Producers, compliance schemes, Policy makers, National authorities and Eurostat.			publication of the data. This would require a low amount of human and financial resources.
4 Create, operate, maintain and update the databases and platforms making the data available on materials contained in stocks and flows of batteries	Researchers, public organisations like Eurostat or private organisations like the Urban Mine Platform	Short Term	High	Take advantage of the existing tools this would require a low amount of human and financial resources.
5. Close cooperation between Battery & WEEE Compliance schemes or compliance schemes covering both Bat & WEEE since greater knowledge on batteries might ensure that EEE producers report correctly.	Battery and WEEE compliance schemes, technical working groups	Medium term	Medium	Would require e.g. the set up of technical working groups to exchange knowledge between Battery- & WEEE compliance schemes
6. Conduct country studies focused on unaccounted waste batteries and the so-called complementary flows (exports of waste batteries, batteries in e-waste, in mixed residual waste etc.) should be done.	European Commission, National authorities, Producers, compliance schemes and Eurostat.	Medium term	Medium	Coordination is needed to apply a harmonised method and get comparable results across the member states. This action would require a medium-large amount of human resource and a medium amount of financial resources.
7. Monitor the stock levels and ages of batteries in households or institutions/ industry (e.g. throughout surveys).	National authorities, compliance schemes and Eurostat.	Short Term	Medium	Coordination is needed to apply a harmonised method and get comparable results across the member states. This would require a low amount of human and financial resources
8. Specify Commision´s definition of several reporting obligations e.g. \`statisically significant´ to ensure harmonised POM numbers Third party audits, financed by producers to ensure reliable numbers.	European Commission	Medium Term	Medium	Coordination is needed to apply harmonized numbers and make sure that definitions are understood by all reporting authorities

Table 2 Summary of key stakeholder groups and key improvement strategies

Stakeholder group	**Stocks and flows covered so far**	**Key improvement strategies**
Public national and European authorities	Portable batteries placed on the market, waste batteries collected and recycled	• Increase the level of details (chemical systems) • Harmonise definitions, data collection methods and documentation • Extend the coverage to automotive and industrial batteries
Battery manufacturers and industry associations	Batteries placed on the market, Lifespan data. Compostion data	• Increase the interoperability and comparability of data by harmonising the classifications of batteries and applications and the units used • Harmonise the level of detail
Organisations collecting waste batteries, compliance schemes	Waste batteries collected, data on residence time and stocks (partly)	• Increase the geographical coverage • Increase the interoperability and comparability of data by harmonising the classifications of batteries and applications and the level of detail

The documentation of the flows of batteries put on the market in EEE should be improved as well. For instance the flows and composition of integrated batteries are difficult to monitor, which leads to inaccuracies and discrepancies between different compliance schemes aiming to reach their targets. Better communication between WEEE compliance schemes and battery compliance schemes is highly recommended to merge knowledge and experiences with WEEE batteries.

3.2 *Tools for harmonizing Batteries data*

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 materials they contain, as well as an analysis of existing battery classifications, a battery Codelist was created based on the different battery electrochemical systems. 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 are further divided into 16 BATT keys. The keys are classified by chargeability type, the Battery Directive descriptions, battery recycling flows and other trade codes such as the EU List of wastes, and CN, and the United Nations Committee of Experts on the Transport of Dangerous Goods (Huisman et al., 2017).

Based on expert knowledge on battery systems and the resources they contain, as well as an analysis of existing battery classifications, an updated version of 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.

Table 3 Battery Codelists (keys, sub-keys & applications) to classify batteries as developed by the ProSUM and ORAMA project

Batt Key	**Description**	**Sub-key**	**Short name**	**Applications**	**Code**
LiRechargeable	Lithium cobalt dioxide (LiCoO2)	LiCoO2	**LCO**	Portable PC	LiCoO2portablepC
				cell phones	LiCoO2cellphones
				Ebikes	LiCoO2ebikes
				Industrial excl mobility	LiCoO2industrial
				camera/games	LiCoO2camera/games
	Lithium iron phosphate (LiFePO4)	LiFePO4	**LFP**	Ebikes	LiFePO4ebikes
				industrial excl mobility	LiFePO4industrial
				others portable	LiFePO4othersportable
	Lithium nickel manganese cobalt oxide (LiNiMnCoO2)	LiNMC	**NMC**	Portable PC	LiNMCportablepc
				Tablets	LiNMCtablets
				cell phones	LiNMCcellphones
				Ebikes	LiNMCebikes
				industrial excl mobility	LiNMCindustrial
				cameras/games	LiNMCcamera/games
				cordless tools	LiNMCcordlesstools

				HEV	LiNMCHEV
				PHEV	LiNMCPHEV
				BEV	LiNMCBEV
				SLI	LiNMCSLI
	Lithium nickel cobalt aluminium oxide (LiNiCoAlO2)	LiNCA	**NCA**	BEV	LiNCABEV
	Lithium manganese Oxide (LiMn2O4)	LiMn	**LMO**	cameras/games	LiMncamera/games
				others portable	LiMnothersportable
				ebikes	LiMnebikes
				BEV	LiMnBEV
				PHEV	LiMnPHEV
				Industrial excl mobility	LiMnindustrial
LiPrimary	Lithium manganese oxide (LiMn2O4)	LiMn	**LMO**	other	LMOprimary
	Lithium Thionyl chloride (LiCFx)	LiCFX	**LCF**	other	LCFprimary
	Lithium Sulfur Dioxide (LiSO2)	LiSO2	**LSO**	other	LSOprimary
	Lithium Iron Disulfide	LiFeS2	**LFS**	other	LFSprimary
	Lithium Thionyl Chloride	LiSOCl2	**LTC**	other	LTCprimary
NiCd	Nickel cadmium (NiCd), sealed	NiCdSealed	**NiCd**	Others portable	NiCdothersportable
				Cordless tools	Nicdcordlesstools
	Nickel cadmium (NiCd), vented	NiCdVented	**NiCd**	industrial excl mobility	NiCdindustrial
	Nickel metal hydride	NiMHSealed	**NiMH**	others portable	NiMHothersportable

NiMH	(NiMH), sealed			Portable pc	NIMHportablepc
				HEV	NiMHHEV
				cordless tools	NiMHcordlesstools
	Nickel metal hydride (NiMH), vented	NiMHVented	**NiMH**	industrial excl mobility	NiMHindustrial
PbA	Lead-acid (PbA), sealed	PbASealed	**PbA**	ebikes	PbAebikes
				others portable	PbAothersportable
				SLI	PbASLI
	Lead-acid (PbA), vented	PbVented	**PbA**	industrial excl mobility	PbAindustrial
Zn	Zinc	Zn	**Zn**	primary	Znprimary
battOther	Others	battOther	**others**	Industrial excl monility	otherindustrial

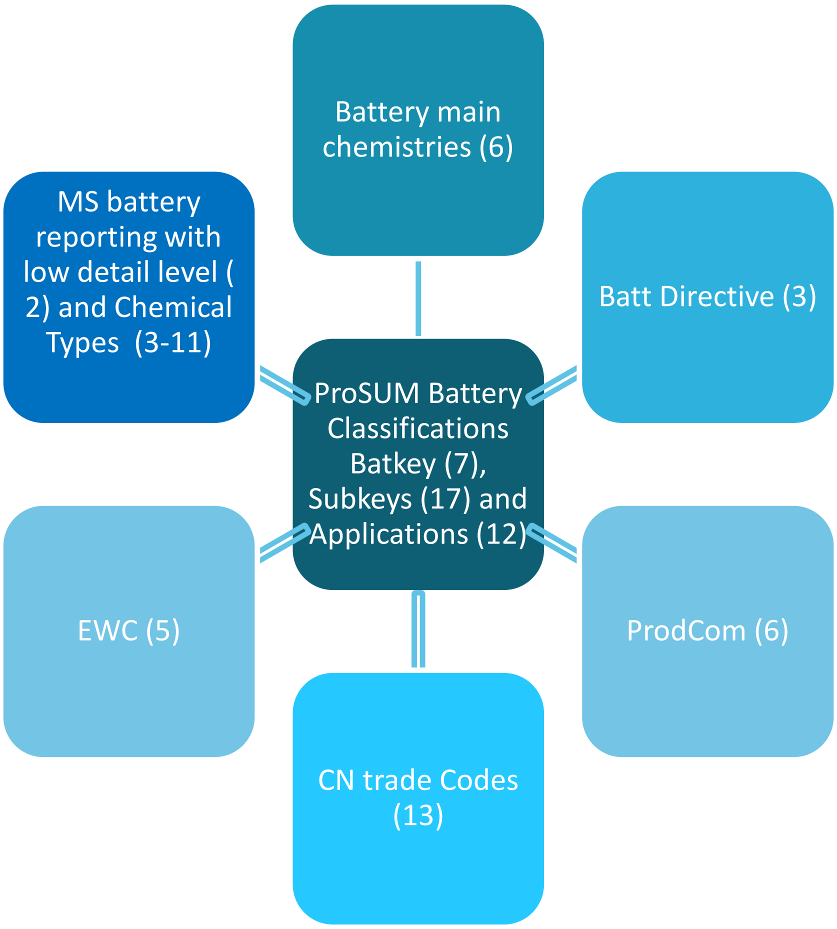

Figure 2 Simplified Classification categories for Battery reporting and relationship with other types of classifications

4 Case studies

In this section, the case studies that were conducted for Batteries within the ORAMA project (D2.3) are described briefly with a view to their teaching approach and a way of showing some best practices.

The case study aims at providing better reporting practices for CRMs flows from batteries in electric vehicles. These batteries were selected due to the high content of CRMs of lithium-based rechargeable batteries and due to the expanding market for electric vehicles.

So far, the data collected at European level by public authorities specified for batteries in electric vehicles is very aggregated, distinguishing between PHEV, HEV and BEV vehicles and does not give enough information to calculate CRMs flows. The ORAMA research aims at describing an advanced data collection system for batteries in electric vehicles including reporting steps in intermediate stages across the battery value chain. Those intermediate steps include for instance data collection by repair and re-use actors. Advanced data could provide stakeholders with an improved knowledge on CRMs from this increasing waste stream. Recommendations will be formulated on the type of data that would be useful at which stage of the system. Furthermore and tool to better classify the collected data will be provided. Next to the battery classifications provided in Chapter 4.2, the case study will develop a guidance document to better classify electric vehicles batteries based on the type of vehicle and model and their feasibility for second life applications.

The need for an improved information base includes several stakeholders and can be summed up in 4 main points:

- In order to be able to give reliable predictions of future supply needs in the rapidly increasing electric vehicles sector, **information on the numbers placed on the market** are necessary in combination with **the battery types** and ideally the **average lifespans to estimate** the return flows in terms of time and total quantities and CRMs. The electric vehicle sector is contributing significantly to the increasing demand for high performance batteries, responsible for large consumption of CRMs.
- **Identify the potential for reuse and remanufacturing of** electric vehicles batteries and identify possible second use applications for instance for power supply
- **Quantify the availability of CRMs for recycling**. This information is particularly interesting for EOL actors in their strategic decisions but also for policy makers and other stakeholders.

1) Perform **valid estimations on recycled materials** on element level

4.1 System overview and data needs

Figure 15 illustrates a comparison of various levels of hybrid vehicle types currently on the market. The hybrid vehicle groups consist of 3 different types of sub-classifications: Micro, Mild and Full Hybrid (HEVs). Even though technically speaking, Plug-in hybrids (PHEVs) also fall under the hybrid classification, they are perceived here as a separate classification since their electric drive is extended which is reflected in the battery types used.

The sources of energy used in HEVs can be a combination of many resources such as battery, petrol, bio-fuels and fuel cells. Looking at the different HEV types (Micro, Mild and Full), they all have intelligent controls to ensure optimum performance of the car engine at its optimum performance zone, by for instance directing any excess energy through e.g. breaking to the battery. Micro-hybrid can be perceived as having the least electrified level, basically being a conventional ICE vehicle with an oversized starter motor to assist the starting of IC engine. Mild hybrids use a motor of 7-15 kW at 60-200 V. The IC engine is constantly running, unless the vehicle has stopped or the speed is very low (Vidyanandan, 2018). A full hybrid can move alone by electricity and run in electric mode. Plug-in hybrid EVs are full-hybrids with a larger battery and a larger motor. Any external power source can be used to charge their batteries unlike other HEV classes where batteries are recharged only by means of the generator or by using the braking energy. Unlike HEVs and PHEVS, battery electric vehicles (BEVs) have only battery as their energy source. To recharge the batteries of a BEV, external power must be plugged into the vehicle to tank up. In electric vehicles, the batteries are thus the counterpart of a fuel tank in conventional cars and represents also the part with the largest weight. Depending on the type and size of the car model, battery capacity 12–18 kWh, the mid-sized ones have 22–32 kWh pack, and the luxury models can have batteries of 60–85 kWh. However battery updates are being increasingly offered by car manufacturers to extend the driving capacity. Due to upgrades or replacement caused by those capacity losses, second hand stakeholders could be faced with a high number of return flows of batteries from BEVs in the near future.

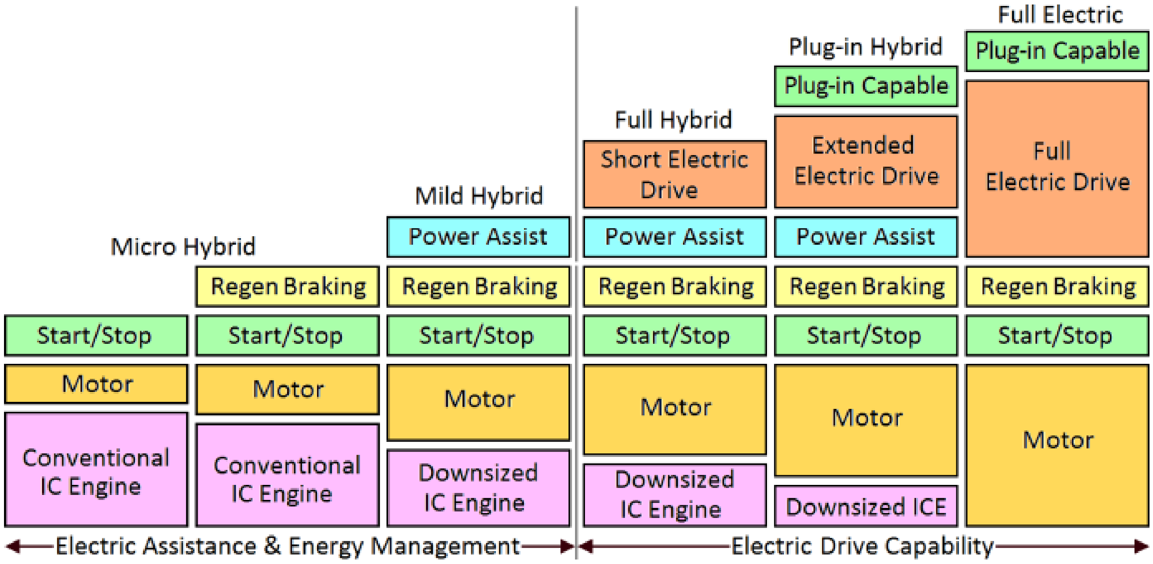

Figure 3: Classifications and features of HEVs, PHEVs and BEVs (Vidyanandan,2018).

The illustration of the stocks and flows of batteries for and in electric vehicles is shown below. The green arrows show the flows that are common, in pieces, for electric vehicles and batteries. For a complete understanding of the stocks and flows of CRMs associated with batteries in electric vehicles, data on volumes and composition of stocks and flows of batteries would be required.

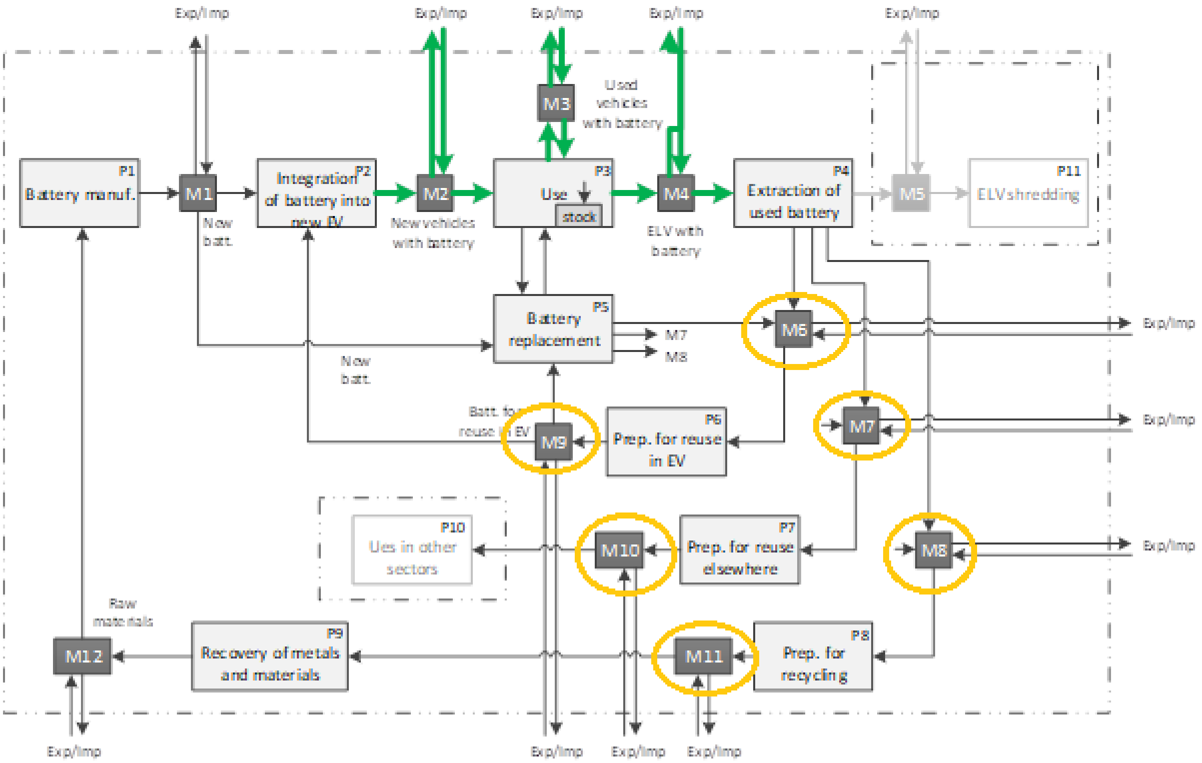

Figure 4: Stocks and flows of batteries for/in electric vehicles. The green arrows indicate the flows that are common to the flows of electric vehicles. The yellow circles indicate reporting requirements for second-life-scenarios.

For complete overview of existing data sources along the xEV value chain and the level of detail see ANNEX 2. The outer system boundary (outer dashed/dotted box) represents the geographical boundaries of a geographical area (European Union or member state). The inner system boundaries (enclosing the processes P10 and P11) serve to exclude some processes, which do take place within the geographical boundaries of the area, but are outside the scope of the present study. Basically, the batteries manufactured in or outside the geographical area (M1) are integrated into vehicles and, together with electric vehicles assembled outside the geographical area, put on the market (M2). Batteries may be integrated into the stocks or exit the stocks (M3) through the trade of second-hand vehicles. Some batteries will be replaced by new and second-hand batteries (P5). At this point in the value chain, the numbers of xEV batteries exceeds the number of units of EVs. At EOL, the batteries are extracted from the EOL vehicles (P4) and either reused in electric vehicles directly or after preparation (P5 and P6), reused in other applications like home energy storage systems (P7) or recycled (P11) to recover raw materials that may be used to manufacture new batteries. In some flows, the number of batteries is expected to equal the number of electric vehicles (green arrows). This is the case for the batteries contained in new electric vehicles put on the market, in traded second-hand electric vehicles with original battery, and in the end-of-life electric vehicles generated.

In order to conduct valid estimations on the magnitude of SRM inherent in the xEV battery system, data collection along the intermediate steps of the inner systems are crucial (marked yellow). Yet, little knowledge is found on this part of the value chain, also due to a lack of reporting obligations. For instance, the lifetime of xEV batteries will determine the timeframe when batteries will move from stock in use (P3) to either P4 or P5, where several second use scenarios may happen. The next actor in the value chain could be a remanufacturer in need of information to determine the optimal second use scenario for the battery to be replaced. The following four main applications for repurposed xEV batteries are currently being used:

1. Residential power storage, mainly in combination with for instance energy from PV panels.
2. Industrial needs e.g. to reduce high energy costs by compensating peak hours
3. Off grid applications to enable people in remote areas with access to electricity
4. Energy storage and utility to compensate for instability in grid electricity

In the decision on what the next step for the battery could be along the value chain, the geometry of a battery is an important driver. Whether the battery pack consist of cylindrical or prismatic battery cells for instance determines the level of reparability or replaceability, since cylindrical cells require more time and effort to be replaced. Information on the battery chemistry and sub-chemistry is yet another important factor for a second-use scenario, since battery chemistries have different technical trade-offs that have to be matched to a corresponding alternative application. Technical properties of a battery to be considered for a second-use application include:

- Energy density
- Specific power
- Durability
- Safety
- Performance
- Lifespan
- Maturity
- Cost

Battery composition and thus CRM content is an important determinator for the technical properties, thus information on the battery sub-chemistries is crucial for a number of stakeholder involved in second-use value chain. Also European EOL actors would benefit significantly from a greater knowledge base on CRM level across the value chain. Their business model relies on the recycling of the materials once final disposal is reached and improved data on CRMs flow in terms of quantity but also timeframe (when are they receiving what) would help them to manage their business models in the future.

The existing sources of data (see ANNEX 3) on batteries in xEVs also shows the gap between current data availability and future data needs which are necessary for European recyclers to predict more reliable second use scenarios of xEV batteries. The boxes in yellow highlight those steps in the value chain with a high potential need for information in the future. Reporting obligations for those steps are currently lagging behind.

4.2 Tools for harmonized data collection of xEV batteries

Lithium-ion batteries consist of a family of sub- chemistries that employ various combinations of materials, which makes the battery able to produce more power or store more energy. Currently, there are five major lithium-ion battery chemistries being used for the EV sector: lithium-titanate (LTO), lithium-nickel-manganese-cobalt (NMC), lithiumnickel- cobalt-aluminium (NCA), lithium-manganese-oxide (LMO) and lithium-ironphosphate- cobalt (LFP) each of which have different characteristics and thus different advantages and disadvantages. Beside the technical specifications, CRMs content differs widely between them. Besides Li-ion batteries, NiMH batteries still play a key role for HEV and PHEVs technologies and contain a variety of CRMs such as REEs and Cobalt.

The method to gather the data for put on the market batteries, as well as the level of detail in which data is collected by national authorities varies considerably across EU Member States (MS) (see also ORAMA Deliverable 2.1). Besides the lack in harmonization of data gathering methods between MS, for the case of xEV batteries two independent sources of data must be combined to get information on the types of batteries embedded in electric vehicles put on the market: the number of electric vehicles put on the market and the types and weight of batteries used in the electric vehicles.

Some MS already give indications on the battery chemical types placed on the market, looking for instance at reporting practices in Belgium, where BEBAT members must distinguish put on the market (POM) numbers by primary and secondary batteries, chemistries and whether they are integrated into EEE or sold separately. Furthermore, BEBAT members are being audited each year to ensure completeness of the data submitted. This information is the first most important step in the value chain, to have better knowledge on what is entering the value chain. However, knowledge on the chemistry level will not be enough to acquire enough knowledge on CRM level. An extra step is needed to move towards sub-chemistry level as recommended in Table 1, since Li-ion chemistries have large CRM variations depending on the anode and cathode materials used which is reflected in the technical properties, see Figure 5.

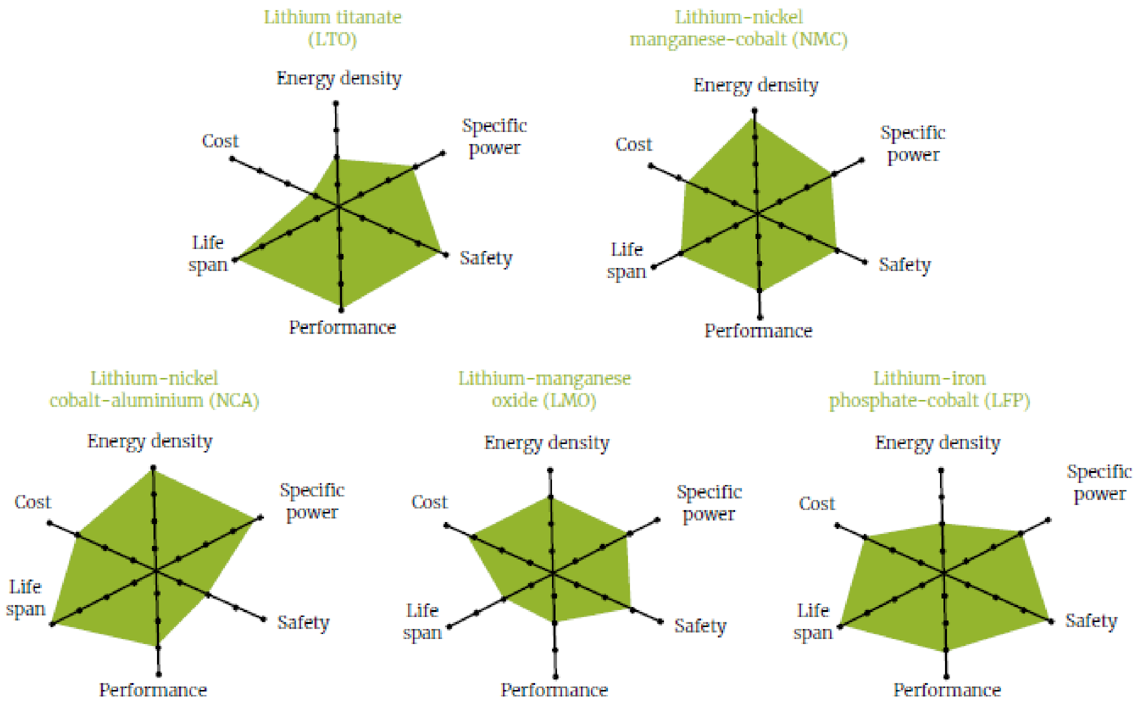

Figure 5 Trade-offs among Li-ion chemistries (Reid &Julve)

In order to ensure harmonization for future reporting practices of batteries, harmonized classification of battery chemistries is proposed as shown in Table 3 to ensure that the level of detailed needed for future second use scenarios of xEV batteries is given. For the case of xEV batteries, information on the geometry of the battery packs used should also be added in the

future to estimate optimal second-use applications for relevant actors in the value chain. Figure 18 provides an example of the data collection used for this case study.
Especially EOL actors in Europe could optimize their recycling processes and better prepare for future business scenarios if such detailed information would be available, since CRM content significantly determines the prices obtained.

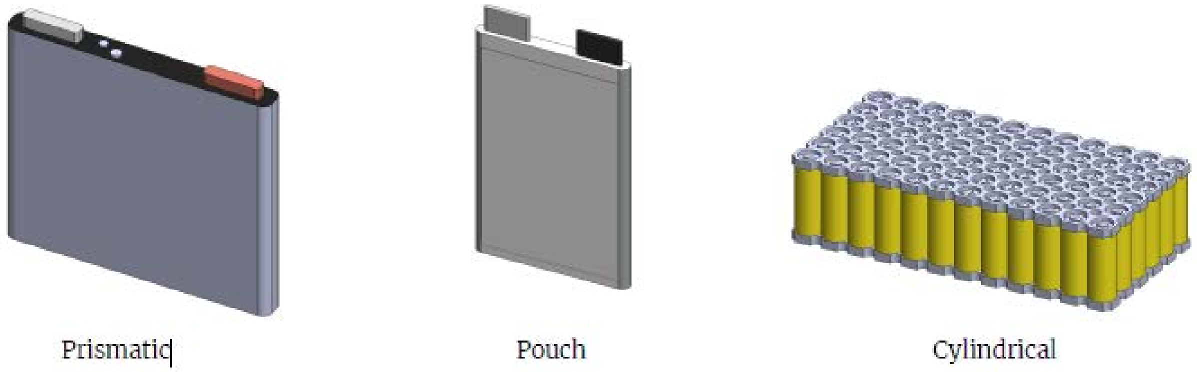

Figure 6 Geometries of the three main battery cells (Reid & Julve,2016)

A decision tree was prepared (for more detail see Figure 19) in line with this case study as a tool for stakeholders along the xEV value chain who are in need to determine the chemical types of batteries found in electric vehicles. Several data sources (academic papers, industry reports, websites) were used to gather the relevant information, since information is widely scattered.

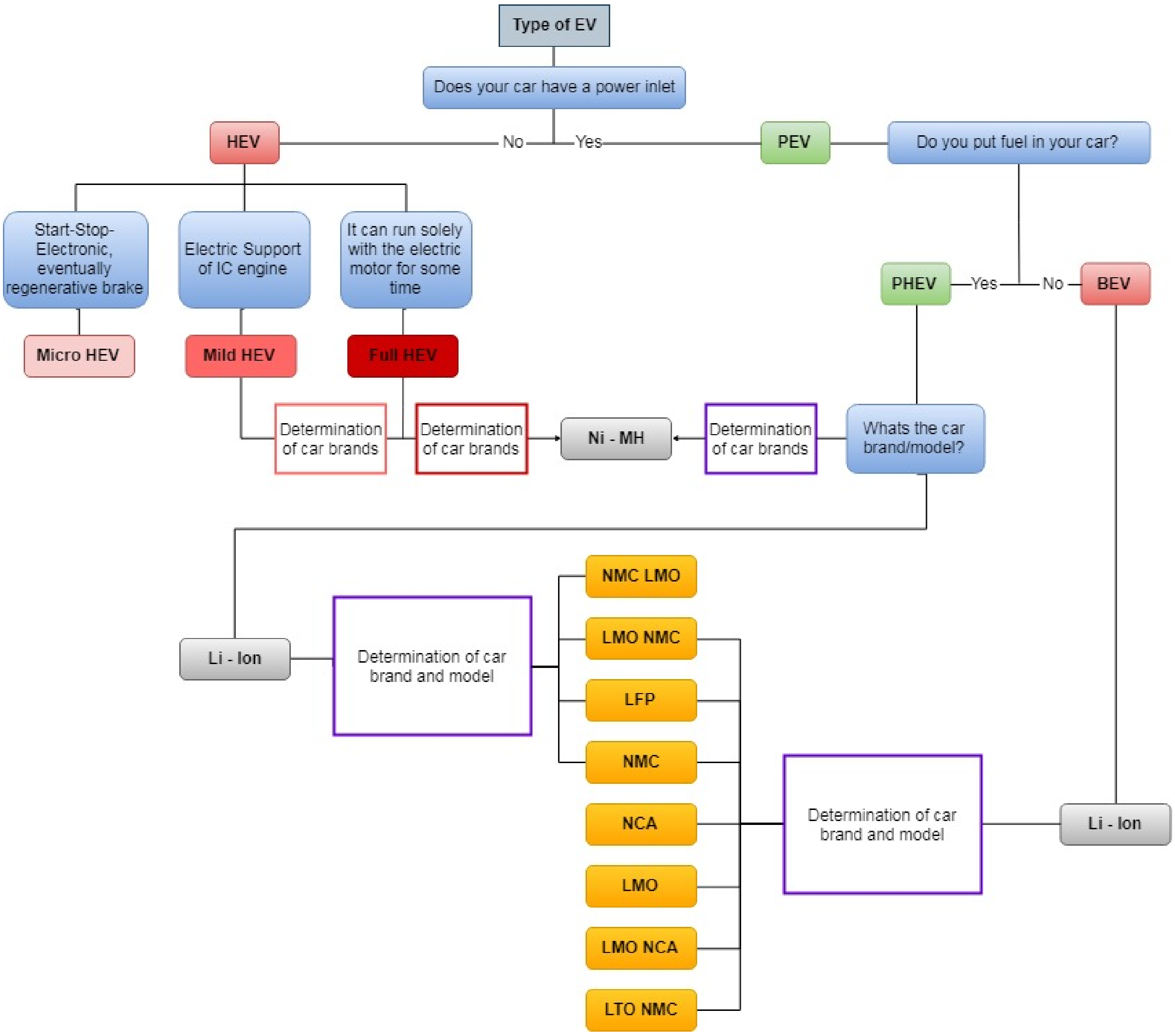

Figure 7 Decision Tree for determination of battery chemistries used in electric vehicles (for more detail see ANNEX 1.

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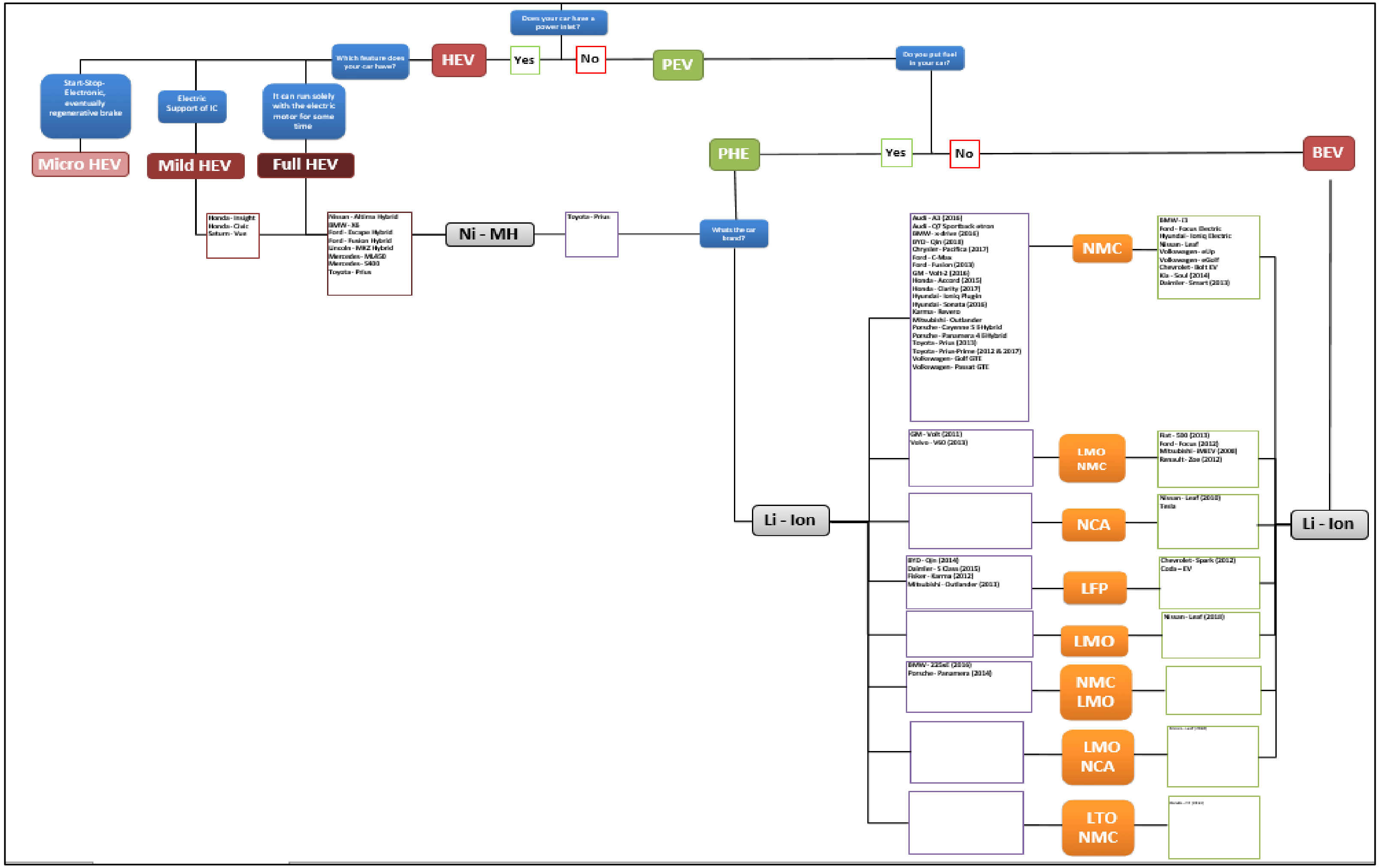
6 Annex

6.1 Annex 1 - Decision Tree for determination of battery chemistry used in xEV



6.2 Annex 2 - Detailed Overview of xEV manufacturers, models and battery information

Manufacturer	Model	Application	Year	BATT key	BATT subkey	Cell Capacity [Ah]	Pack Capacity [kwh]	Bat. Gemotery
Audi	A3	PHEV	2016	Li Ion	NMC	25,0	7,50	no information
Audi	Q7 Sportback eTron	PHEV	2017	Li Ion	NMC		17,30	no information
Audi	A3 Sportback eTron	PHEV	2017	Li Ion	NMC		8,80	no information
BMW	i3	BEV	2017	Li Ion	LMO/NMC		33,00	no information
BMW	X6	Full HEV	<= 2013	Ni MH				no information
BMW	xDrive	PHEV	2016	Li Ion	NMC	26,0	9,20	no information
BMW	225xE	PHEV	2016	Li Ion	NMC/LMO	26,0	7,60	no information
BYD	E6	BEV	2017	Li Ion	LFP		82,00	no information
BYD	Qin	PHEV	2014	Li Ion	LFP	40,0	13,00	no information
BYD	Qin	PHEV	2018	Li Ion	NMC	42,0	14,00	no information
GM	Spark	BEV	2012	Li Ion	LFP	20,0		Pouch
Chrysler	Pacifica	PHEV	2017	Li Ion	NMC	46,0	16,00	no information
Daimler	Smart	BEV	2013	Li Ion	NMC	52,0		Pouch

Daimler	For Two Electric Drive	BEV	2017	Li Ion	NMC		18,00	no information
Daimler	S Class	PHEV	2015	Li Ion	LFP	21,0	6,50	no information
Fiat	500	BEV	2013	Li Ion	LMO/NMC	63,0		Prismatic
Fiat	500e	BEV	2017	Li Ion	NMC		24,00	no information
Fisker	Karma	PHEV	2012	Li Ion	LFP	20,0	20,00	no information
Ford	Focus	BEV	2012	Li Ion	LMO/NMC	16,0		Pouch
Ford	Focus Electric	BEV	2017	Li Ion	NMC		33,50	no information
Ford	Escape Hybrid	Full HEV	<= 2013	Ni MH				no information
Ford	Fusion Hybrid	Full HEV	<= 2013	Ni MH				no information
Ford	C Max	PHEV	2013	Li Ion	NMC	24,0	7,60	no information
Ford	Fusion	PHEV	2013	Li Ion	NMC	24,0	7,60	no information
GM	Bolt EV	BEV	2017	Li Ion	NMC		60,00	no information
GM	Volt 1	PHEV	2011	Li Ion	LMO/NMC	15,0	16,00	no information
GM	Volt 2	PHEV	2016	Li Ion	NMC	26,0	18,40	no information
GM	Volt	PHEV	2017	Li Ion	NMC		18,40	no information
Honda	Fit	BEV	2013	Li Ion	LTO/NMC	20,0		Prismatic

Honda	Insight	Mild HEV	<= 2013	Ni MH				no information
Honda	Civic	Mild HEV	<= 2013	Ni MH				no information
Honda	Accord	PHEV	2015	Li Ion	NMC	21,0	6,60	no information
Honda	Clarity	PHEV	2017	Li Ion	NMC	25,0	17,00	no information
Hyundai	Ioniq Electric	BEV	2017	Li Ion	NMC		28,00	no information
Hyundai	Sonata	PHEV	2016	Li Ion	NMC	27,0	9,80	no information
Hyundai	Ioniq Plug In	PHEV	2017	Li Ion	NMC		8,90	no information
Karma	Revero	PHEV	2017	Li Ion	NMC		21,40	no information
Kia	Soul	BEV	2014	Li Ion	NMC	38,0		Pouch
Lincoln	MKZ Hybrid	Full HEV	<= 2013	Ni MH				no information
Mercedes	B Class E Drive	BEV	2017	Li Ion	NCA		36,00	no information
Mercedes	ML450	Full HEV	<= 2013	Ni MH				no information
Mercedes	S400	Full HEV	<= 2013	Ni MH				no information
Mitsubishi	iMiEV	BEV	2008	Li Ion	LMO/NMC	50,0		Prismatic
Mitsubishi	Outlander	PHEV	2013	Li Ion	LFP	21,0	12,00	no information
Mitsubishi	Outlander	PHEV	2017	Li Ion	NMC		12,00	no information

Nissan	Leaf	BEV	2018	Li Ion	LMO			no information
Nissan	Leaf	BEV	2010	Li Ion	LMO/NCA	33,0		Pouch
Nissan	Leaf	BEV	2017	Li Ion	NMC		30,00	no information
Nissan	Altima Hybrid	Full HEV	<= 2013	Ni MH				no information
Porsche	Cayenne S eHybrid	PHEV	2017	Li Ion	NMC		10,80	no information
Porsche	Panamera 4 eHybrid	PHEV	2017	Li Ion	NMC		9,40	no information
Porsche	Panamera	PHEV	2014	Li Ion	NMC/LMO	26,0	9,40	no information
Renault	Zoe	BEV	2012	Li Ion	LMO/NMC	36,0		Pouch
Saturn	Vue	Mild HEV	<= 2013	Ni MH				no information
Tesla	Model S 75D	BEV	2017	Li Ion	NCA		75,00	Cylindrical
Tesla	Model S 90D	BEV	2017	Li Ion	NCA		90,00	Cylindrical
Tesla	Model S 100D	BEV	2017	Li Ion	NCA		102,00	Cylindrical
Tesla	Model S P100D	BEV	2017	Li Ion	NCA		102,00	Cylindrical
Toyota	Prius	Full HEV	<= 2013	Ni MH				
Toyota	Prius Prime	PHEV	2012	Li Ion	NMC	22,0	4,50	
Toyota	Prius Prime	PHEV	2017	Li Ion	NMC	25,0	8,80	
Toyota	Prius Prime	PHEV	2017	Li Ion	NMC		8,80	
Toyota	Prius	PHEV		Ni MH				
Volkswagen	eUp	BEV	2017	Li Ion	NMC		18,70	

Volkswagen	eGolf	BEV	2017	Li Ion	NMC		35,80	
Volkswagen	Golf GTE	PHEV	2017	Li Ion	NMC		8,80	
Volkswagen	Passat GTE	PHEV	2017	Li Ion	NMC		9,90	
Volvo	V60	PHEV	2013	Li Ion	LMO/NMC	15,0	11,00	

6.3 *Annex 3 - Overview of Existing data sources and needs for data for the flows and stocks of batteries from electric vehicles*

Flow or stock	**Data needed**	**Existing data sources**	**Need for new data**	**Relevance***
P1→M1	Volumes of EV batteries produced within the geographical area, composition	Unpublished or commercially available market research data from institutes like Avicenne	Combine the efforts with the Batteries Initiative (to enhance the battery production within Europe), which also needs data monitoring	Medium
M1→P2+P5	Put on the market of EV batteries within the geographical area	Unpublished data from battery manufacturers	Collection of data by Eurostat? Batteries directive?	high
M1→P2	Integration of batteries into new vehicles produced within the geographical area			Medium
M1→P5	Replacement of batteries by new batteries of vehicles in-use within the geographical area	/	Information on numbers of Battery and chemical types from dismantlers and repair shops	High
M9→P5	Replacement of batteries by re-used or re-manufactured battery of vehicles in-use within the geographical area	/	Information on numbers of batteries being replaced with corresponding chemistry types and Cars being re-put on the market	Medium
M2→P3	Volumes of new xEV put on the market in the geographical area (EU or national markets) with information on the battery sub chemistry used	Eurostat: vehicles using “alternative fuel” with classifications HEV, PHEV and BEV; Comtrade since 2017 (HEV, PHEV and BEV) International Council on Clean Transportation, EV-Volumes; National register organisations (Norway, Switzerland) Forecasts of volumes of EV put on the market: Edison Electric Institute (EEI) and the Institute for Electric Innovation (IEI, Bloomberg New Energy Finance, Statista, Morgan Stanley, Wood Mackenzi etc. EV BATT: Avicenne (differentiates LiMn, LiNMC, NiMH) Creation Inn Eucobat, compliance schemes, national authorities	Harmonized classification system to enable a uniform data reporting with a higher level of detail (distinguishing between different sub-chemistries used in EVs)	High

Flow or stock	Data needed	Existing data sources	Need for new data	Relevance*
M2→P3	Composition	Material safety data sheets Literature RECHARGE: General data on LiMn, LiNMC, NiMH, no data on electronics Nationale Plattform Elektromobilität Data on the average weights of Li-ion and NiMH used in HEV, EV and PHEV communicated to Eucobat	Requirements for producers to provide composition data with a defined level of details.	High
M3→P3	Volumes of second-hand vehicles containing an xEV battery bought in the geographical area (EU or national markets)	registration of second-hand vehicles	Specification of the type of xEV and the type of battery used.	Medium
P3	Use - stocks	Registered EV. Measured data on stocks can be compared to modelled data (requiring historic data on POM, lifetime of batteries and lifetime of vehicles)	Extend the data on battery stocks gathered through harmonized surveys	High
P3	Use - lifetime	Estimates from experts/RECHARGE (8 years), Producer data from EMPA, (partly confidential)	Improve data on xEV lifetimes to estimate rates of return. Results e.g. from JRC technical group working on lifetimes	High
P3→M3	Vehicles for second-hand trade	Deregistration of vehicles that are sold as second-hand	Specification of the type of xEV that indicates which type of battery is used inside.	Medium
P3→M4	Waste generation: Vehicles that have reached end-of-life	Deregistration of vehicles that have reach end-of-life, computed data on waste generation	Specification of the type of xEV that indicates which the type of battery is inside.	High
M4→P4	ELV collection	Eucobat, compliance schemes, national authorities?	Collection of EVs distinguishing between xEV types and corresponding battery chemistries used. New data in Eurostat from the coming revised batteries directive?	High

Flow or stock	Data needed	Existing data sources	Need for new data	Relevance*
P4→M8	Waste batteries separated from ELV available for recycling		Collection of waste EV batteries separated during treatment of electric ELV Information on the numbers, weights and types of EV batteries separated or received for recycling	High
P5→M8	Waste batteries separated during xEV repair available for recycling		Collection of waste xEV batteries separated during repair	High
M8→P8	xEV waste batteries arriving at recycling facilities for waste batteries	Eurostat data on lead and cadmium, not distinguishing xEV batteries compliance schemes, national authorities?	Reporting of battery recyclers on recycled CRMs	High
P9→M12	Put on the market of secondary materials from waste EV batteries	Eurostat data on lead and cadmium, not distinguishing xEV batteries Data to calculate the recycling efficiency	Extension to further materials	Medium
Existing estimates of CRM flows in xEV batteries	Data from the entire value chain, including forecasts	European Commission: Report on Raw Materials for Battery Applications; Study on the review of the list of Critical Raw Materials, Critical Raw Materials Factsheets, June 2017 JRC: Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU (2016); Lithium-ion battery value chain and related opportunities for Europe (2016) Agora Verkehrswende: Strategien für die nachhaltige Rohstoffversorgung der Elektromobilität (in German) Circular impacts: Circular economy perspectives for future end-of-life EV batteries	Consolidation of the data, building of a centralised harmonised database	High

* Relevance for understanding the flows and stocks of CRM to provide useful data to policy makers and other stakeholders