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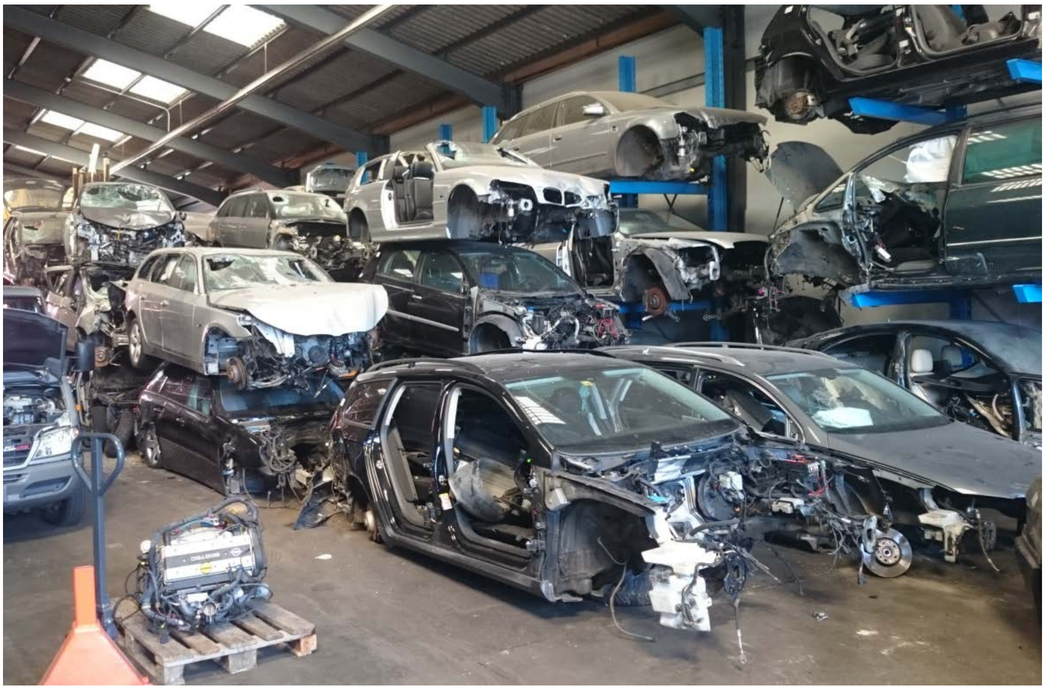
Technical Guideline
Tools for harmonization of data collection on ELV

Related to Deliverable 2.3 and 4.1



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A.N. Løvik, cover p. 1, ELVs being dismantled

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 includes material 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

ACEA: European Automobile Manufacturers' Association

ATF: Authorized Treatment Facility

BEV: Battery Electric Vehicle

CN: Common Nomenclature

CRM: Critical Raw Materials

EGARA: European Group of Automotive Recycling Associations

ELV: End-of-Life Vehicle

EC: European Commission

EOL: End of Life

EURMKB: European Raw Materials Knowledge Base

HEV: Hybrid Electric Vehicle

ICEV: Internal Combustion Engine Vehicle

IMDS: International Material Data System

ITF: International Transport Forum

LIB: Lithium-Ion Battery

LPG: Liquefied Petroleum Gas

MS: Member States

NG: Natural Gas

PHEV: Plug-in Hybrid Electric vehicle

RM: Raw Material

RMIS: Raw Materials Information System

SRM: Secondary Raw Materials

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

UNECE: United Nations Economic Commission for Europe

WEEE: Waste Electrical and Electronic Equipment

xEV: Electric vehicles; collective term for HEV, PHEV and BEV

1 Introduction

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). To this end, the ORAMA 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). More specifically, ORAMA provides 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, ORAMA produce technical guidelines describing best practices related to the provisioning of data for SRM. These guidelines 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. The technical guidelines feed into training material that will be used in a workshop and webinars (Task 4.2).

Whereas this document contains information and tools for ELV in particular, the Deliverables 2.2, 2.3, 4.1, and 4.2 of the ORAMA project also contain results, recommendations, case studies, and tools for ELV as well as for WEEE, Batteries 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 are 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 guideline:

- Section 1 Brief introduction; overview of the scope, target audience, aim and future application.
- Section 2 Description of the importance of a proper systematization and harmonisation of data on SRM and its current status in Europe for ELV.

- Section 3 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 on vehicles and ELVs. In addition this section aims to provide a detailed description of other Tools developed in D2.3 from the case studies for ELV in the ORAMA project.
- Section 4 Description of the ELV ORAMA´s case study.
- Section 5 References

2 Importance of systematization and harmonisation of data on SRM in ELV

2.1 Legal frame and relevance of reporting

2.1.1 In-use stocks and new registrations

Eurostat publishes statistics on the number of vehicles in stock and new registrations as part of the transport statistics. The data is collected through "the Common Questionnaire for Transport Statistics", developed in co-operation between the United Nations Economic Commission for Europe (UNECE), the International Transport Forum (ITF) and Eurostat (Eurostat, 2014). The data collection is not supported by a legal act, and the completeness of the data varies from country to country. Geographically it covers the EU Member States, EFTA states and Candidate countries to the EU. The data are reported annually.

The statistics on in-use stocks and new registrations are ultimately based on primary data from the central vehicle registry in each country. These central vehicle registries keep track of all vehicles registered for use on public roads and contain very detailed information about the vehicles as well as personal information about their owners. Data collection to the national central vehicles registries depends on national practice and the amount of information available therefore varies between countries. Before being submitted to Eurostat via the questionnaire, the data are processed, aggregated and controlled by the national authorities. The aggregation of the data, using the Eurostat classification system for vehicles, reduces the amount of information contained in the dataset substantially, but also ensures harmonization of data from different countries.

2.1.2 Collected ELVs and treatment

Member States are required to report data on collected ELVs to Eurostat to enable the calculation of recycling- and recovery rates, and thereby assess Member States' compliance with the targets defined in the ELV directive. The directive only encompasses vehicles below 3.5 tonnes. Heavier vehicles are not included, so there is no obligation to report nor collect statistics on their end-of-life treatment. Eurostat publishes yearly data on the number and mass of collected ELVs, as well as various material flows related to the treatment of ELVs in all EU Member States except Malta and Croatia plus the non-EU states Norway and Liechtenstein (28 countries in total) (Eurostat, 2019). The minimum required reporting from each state includes the number and mass of generated and collected ELVs, the total mass of materials and components dismantled, mass of shredder outputs (ferrous metals, non-ferrous materials, shredder light fraction, others), and exports of ELVs and materials from ELV treatment. In voluntary parts of the reporting, some Member States report more detailed data on the outputs from depollution and dismantling, including the mass of batteries, liquids, oil filters, catalysts, metal components, tyres, large plastic parts, glass and "other materials".

The main sources of original data are authorised treatment facilities (ATFs) that dismantle and depollute the vehicles and shredder facilities that mechanically treat vehicle hulks to generate recyclable materials. Additional data sources used include producers and importers, central vehicle registries, surveys, and shredder trials.

The data prepared by the responsible organization is reported annually to Eurostat. Along with the data, the Member States are required to submit a quality report that describes the data collection procedures and analysis. However, there is no obligation regarding the structure and content of the quality reports, and they are normally not made publicly available.

The extent and level of detail of reported data on ELVs and their treatment are the result of the requirements defined in ELV directive. The European Commission has a legal obligation to review the directive by 31 December 2020 and if necessary propose legislative changes (European Commission, 2019a). A public stakeholder consultation takes place from August to October in 2019 (European Commission, 2019b). The review of the directive will focus on the unknown whereabouts of ELVs and the possibility of setting material-specific recycling and recovery targets. This could potentially lead to a requirement for collecting additional, more detailed data.

2.2 Differences in scope and data collection that require harmonisation

2.2.1 In-use stocks and new registrations

The data on in-use stocks and new registrations from different countries are harmonized through the Eurostat vehicle classification system, which is very similar to the classification system used in the ProSUM project. In both cases, vehicles are classified according to four properties: type (whether it is a car or a van), mass (divided in 4 categories), engine size (divided in four categories + a category for no engine) and "motor energy type". The latest Eurostat classification system allows for distinguishing, among others, battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), non-plug-in hybrid electric vehicles (HEV), diesel, petrol and "other" vehicles. Note that although Eurostat provides various tables where cars are classified according to mass, motor energy etc., it is not possible to download the data with full resolution, i.e. grouped by type, mass, engine size and motor energy at the same time.

It is important to note that both the registration of primary data in the central vehicle registries and the compilation of statistics, such as done by Eurostat, are done for other purposes than the prospection of secondary raw materials. Therefore it is not surprising that these statistics do not always contain the desired level of detail and required types of information.

There are two data collection/compilation steps to consider regarding the statistics on passenger cars in the stock and new registrations: 1) collection of primary data in the central vehicle registry of each country, and 2) aggregation and compilation of data from the central vehicle registries to aggregated statistics such as in Eurostat. Here we mainly address the second step, since we have very limited information on the data collection practices for the central vehicle registries in individual countries. As the vehicle classification system determines how data from different countries are harmonized, the main question becomes: which classification system will ensure that sufficient information and level of detail for prospection of secondary raw materials is retained in the aggregated statistics? Furthermore we may ask whether the required information for adopting a given new classification system already exists in central vehicle registries (in which case implementation of a new system should be straight-forward) or whether it requires changes to the national practice for data collection to the central vehicle registry.

The following issues with the existing classification system have been identified:

- The emergence of vehicles with electrified drivetrains makes a further distinction between different types of electric and hybrid vehicles necessary. This has partly been addressed, as the statistics includes a differentiation between BEV, PHEV and HEV since 2013. However, the statistics do not contain enough information to provide robust estimates of the content of SRMs in these vehicles, e.g. since there is no information about the power or the battery capacity nor the capacity of electric traction motors of the vehicles.

- The classification system focuses on main extensive characteristics of the vehicles (mass and engine size), which however are not directly linked to the equipment level of the vehicles and therefore to their significant SRM content. If the vehicle segments commonly referred to in the automotive industry could be standardized and constant over time, these may allow a more representative classification of equipment levels.
- The quantitative characteristics (mass and engine size) are described by 4 relatively crude categories, resulting in a very large number of cars belonging to the same category. Moreover, the boundaries of the categories may not be ideal considering the typical mass and engine size of new vehicles today, which means that large shares of vehicles belong to the uppermost categories.
- The information collected on collected ELVs do not contain any information on the type of vehicles, such as drivetrain types nor the age of vehicles. It is thus not possible to align the ELV data with that of new registrations and in-use stock.
- In the in-use stock data, vehicles are also classified according to age groups (<2 years, 2-5 years, 5-10 years, 10-20 years, >20 years). It would be useful to provide these data on individual years instead.

3 Prioritised recommendations and actions to improve reporting of ELV

3.1 Prioritised recommendations for ELV from the ORAMA project

In the ORAMA report D2.2 a set of recommended actions for improved data management of SRM in vehicles was provided. The actions with a high priority and assumed of reasonable feasibility are given in Table 1, visualized in Figure 1, and are shortly elaborated here. More background can be found in D2.2 chapters 3.2 and 3.3.

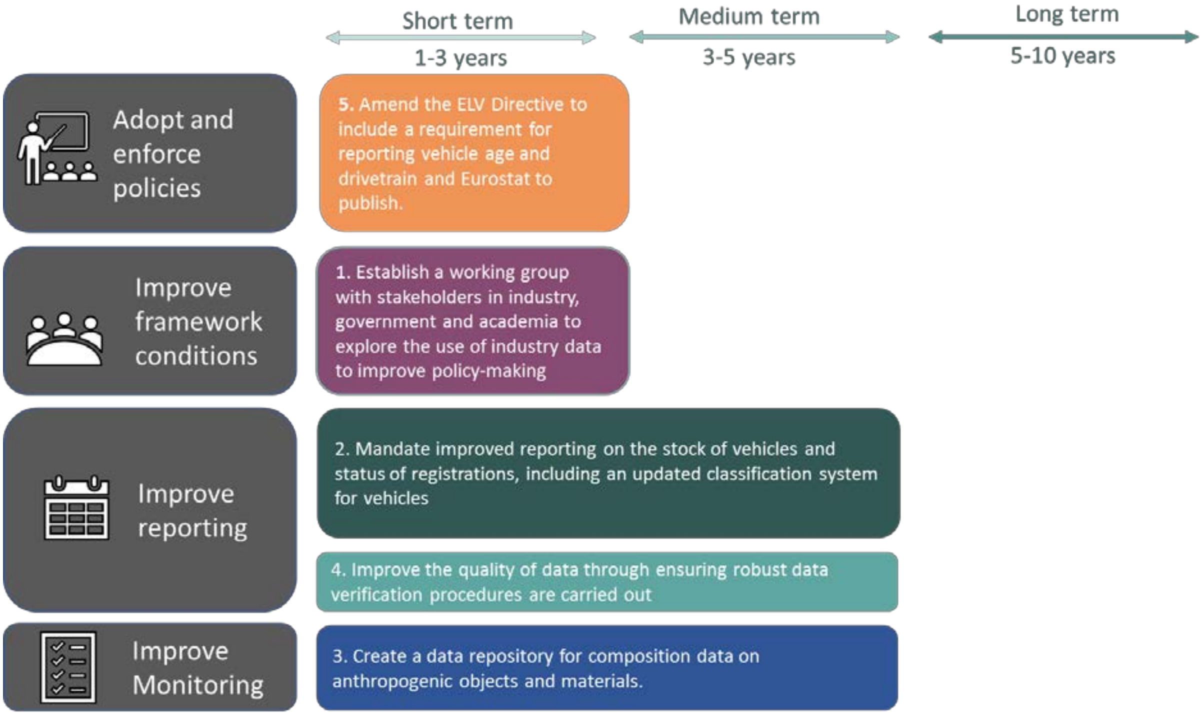

Figure 1 Prioritized recommendations for ELVs.

1. The existing data systems used within the vehicle industry including its supply chains (e.g. IMDS) contain detailed information of components' material compositions and weights. It is, however, not publicly accessible due to confidentiality. Neither does the vehicle industry appear to prioritize keeping track on SRM for recycling and similar purposes.

   It is recommended that a working group involving vehicle manufacturing and recycling industries is established with support from reporting authorities and the SRM research community. The aim is initially to explore possibilities to best utilize the already existing information and information infrastructures within the vehicle industry to identify and communicate components to be dismantled for SRM recovery. The working group should also serve as a stakeholder forum for development of ELV management policy in general.

2. Information about SRM total amounts in vehicles hinges on the availability of basic information about the vehicle stock. The reporting routines, completeness and transparency vary among MS. As the material composition varies between ICEV and EV, PHEV and HEV, and for some SRM varies substantially, there is also a need to

update vehicle classification as the stocks of vehicles with electrified drivetrain have grown to significant levels. Results from the ORAMA case study on BEV, PHEV and HEV batteries in Norway (section 4) have shown that the vehicle classification used in ProSUM and by Eurostat does not provide much distinction between different types of BEV, PHEV and HEV. For example, more than 98% of the stock of PHEV belongs to the same mass category.

It is recommended to further diversify the classification with additional mass categories, as well as adding information related to the electric drivetrain (e.g. battery capacity and power of the electric motor). However, the feasibility of the latter depends on these data being collected by the national authorities. Furthermore, it is important to capture changes over time in vehicle technologies. One prominent example is traction batteries for which efficiencies and specific chemistries change rapidly affecting the SRM content.

Implementation of a consistent mandatory reporting procedure from MS to EC for vehicle stock and status of registrations is recommended. See also suggested update for vehicle classification in Section 3.2.

3. Information about the composition of components and materials is increasingly generated by researchers. The information is however scattered in various locations and formats, such as scientific articles, technical reports and semi-structured datasets.

   The establishment of a data repository where such information can be collected, sorted and easily retrieved is recommended. A success factor is incentivising researchers to publish data in this way.

4. The reliability of data collected and published in Eurostat varies as quality control procedures vary. Uncertainty levels are in general difficult to assess and must often be based on assumptions.

   It is recommended that EC and Eurostat collaborate to develop and implement robust data verification procedures.

5. Information about characteristics of the collected ELVs is less detailed than that of new registrations and in-use stock. Alignment of data representing the full vehicle lifecycles is thus not possible. Also, this affects the uncertainty of estimated SRM composition available for recycling since SRM contents vary over time and type of vehicles.

   It is recommended that the ELV directive is amended to include the vehicle model year and drivetrain in the certificates of destruction issued for all recycled vehicles, reported to and subsequently published by Eurostat.

Table 1 prioritized recommendations for ELVs

Action	Stakeholders Involved	Time Frame	Priority	Feasibility
1. Establish a working group to explore the possibility of using manufacturers' composition data (e.g. from IMDS) for: 1) identification of components to be dismantled for SRM recovery; 2) development of ELV management policy in general.	European Commission, ACEA, EGARA, researchers (ORAMA partners)	Short term	High	Depends on industry's willingness to cooperate. The main constraint is related to respecting confidentiality of data.
2. Mandate improved reporting on the stock of vehicles and status of registrations, including an updated classification system for vehicles.	EC, Eurostat	Short term	High	The feasibility is high, but depends to some extent on whether sufficient primary data (e.g. on power of electric vehicles) is collected in the national central vehicle registries.
3. Create a data repository for composition data on anthropogenic objects and materials.	ORAMA partners (+ other researchers)	Medium term	High	Technically very feasible. It will be challenging to convince researchers to use such a repository, and to ensure long-term financing. Requires substantial human resources for initial development, and afterwards a smaller amount of human resources and IT infra-structure (servers) for maintenance.
4. Improve the quality of data through ensuring robust data verification procedures are carried out.	Eurostat, EC	Medium term	High	This requires procedure development to improve data quality and it is fairly feasible through a collaboration between Eurostat and EC.
5. Amend the ELV Directive to include a requirement for reporting vehicle age and drivetrain and Eurostat to publish.	Eurostat, EC	Short term	High	Technically very feasible since certificates of destruction are issued for individual vehicles.

Additional recommended actions were provided in D2.2 of either lower priority or with low feasibility. This includes addressing the issue of ‘unknown whereabouts’ of vehicles and data harmonization within the automotive industry.

The ProSUM project (Huisman et al., 2017) identified a significant gap between estimated de-registrations and reported collected ELVs (7 million tonnes). A large number of vehicles is hence of unknown whereabouts and, subsequently, so is a significant amount of potentially recoverable SRM. However, there is low feasibility to fill this knowledge gap as it would require major data improvement and harmonization for registration and de-registration, some of which would be at least improved upon by the recommended actions 2, 3, and 5 above. In addition, there are several stakeholders that are involved in the process including car owners. While the issue of unknown whereabouts is significant and hence of high priority, before recommending further specific actions a better understanding through research may be called for.

The companies within the automotive industry have developed different information tools and infrastructures to monitor components and materials to manage specific technical, economical and legal requirements. These systems are not always compatible with each other in terms of nomenclature, format, coverage; different manufacturers have a different setup of tools, etc. The ability to consistently monitor SRM in vehicles at the levels of member states or the EU would be improved if the automotive industry harmonized their own data management and tools. However, such an effort must be driven from within the industry and is deemed very challenging due to the complexity of diversity of components, materials and naming conventions.

The ORAMA ELV case study focused on Li-ion batteries in electric vehicles. The findings and experiences from the study also supports the recommended actions provided on batteries in general, see the Technical Guideline Tools for harmonization of data collection on Batteries, Emmerich et. al., 2019.

3.2 *Tools for harmonizing ELV data*

Based on the results of the case study on batteries in xEV in Norway, it is recommended to revise the vehicle classification system used by Eurostat (and others) to compile statistics on vehicle registrations. The proposed new classification system, which includes new categories of mass, is shown in Table 2.

Table 2 Proposed new classification system for vehicles. Categories that are new compared to the current Eurostat classification are shown in red.

Type	***Motor energy***	***Engine size***	***Mass***
unknown	unknown	unknown	unknown
car	petrol	< 1400 cm3	< 1000 kg
van	diesel	1400-1999 cm3	1000-1249 kg
	LPG	> 2000 cm3	1250-1499 kg
	NG	no cylinder	1500-1749 kg
	HEV		1750-1999 kg
	PHEV		2000-2249 kg
	BEV/fuelcell		2250-2499 kg
	other		>2500 kg

4 Case studies

In this section we present the main findings of the case study on batteries in xEV in Norway. For a detailed explanation of the methods and results, see ORAMA Deliverable report D2.3.

The rapid penetration of electric vehicles, including full battery electric vehicles (BEV), hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV), is causing a steep increase in the production and use lithium-ion batteries (LIBs) and partly also nickel metal hydride (NiMH) batteries. The growing stock of rechargeable batteries in use is a potential future source of secondary raw materials such as cobalt, lithium, nickel, light rare earth elements and graphite, most of which are associated with concerns over long-term supply from primary sources. Due to the lifespan of vehicles and their batteries, the number of batteries reaching end-of-life is still small, despite fast growth in electric vehicle sales. It is expected that these amounts will grow substantially in the coming years. The number of batteries available for material recovery also depends on the extent to which the batteries are repaired and remanufactured and/or reused in other applications such as energy storage in buildings.

In anticipation of these changes, it is important to provide estimates of the amounts of rechargeable batteries of various types that reach end-of-life and are made available for material recovery, repair, remanufacturing and reuse in other applications. Such information will help policy-makers and industry to prepare for dealing with this new waste stream, by establishing appropriate take-back systems and ramping up the capacity of recycling/repair/remanufacturing infrastructure. In addition to forecasting future end-of-life battery flows, it will be necessary to closely monitor the current system at any given time to identify options for improvement. Both of these objectives require data that to a large extent are not readily available today.

In this case study, we take a closer look at the stock of BEVs, HEVs and PHEVs (collectively referred to as xEVs) in Norway and the batteries contained in these, focusing on the classification of vehicles and availability of data on battery mass, type and composition. Firstly, by analyzing the vehicle stock data we can identify to which extent the current vehicle classification system is able to distinguish between different xEVs, and we can already provide some recommendations regarding how to define a more useful classification system. Secondly, we use the data on the vehicle stock together with data on the battery type and mass per vehicle to estimate the stock of xEV batteries in Norway. This stock estimation is done using four different vehicle classification systems:

- PS1: xEV are classified only based on their fuel type. The only three categories are hence BEV, PHEV and HEV.
- PS2: We follow the Eurostat classification and group vehicles based on their fuel type and mass (in the following categories: < 1000 kg, 1000-1249 kg, 1250-1499 kg and > 1500 kg.
- O1: We follow the Eurostat classification but extend it with additional mass categories at 250 kg intervals up to 2500 kg.
- O2: We consider each brand-model-fueltype combination individually. The only grouping that takes place here are the variations (e.g. over time) for a specific model.

We collected data on the battery pack mass, cell mass and type of battery in specific vehicle models from a variety of data sources. The main data sources are: 1) United States Environmental Protection Agency document database, that includes applications for approval of electric vehicle models (United States Environmental Protection Agency (EPA), 2019); 2) a recent review paper about lithium-ion battery technology by Zubi et al. (Zubi et al., 2018); 3) Battery University web page (Battery University, 2019); Toyota service information web page (for hybrid vehicles) (Toyota, 2019).

We found data on the battery pack mass and chemistry for 23 different car models, including BEVs, PHEVs and HEVs. Note that this number does not include variations in battery size within each model (e.g. Tesla S has been sold with at least 6 different battery sizes depending on model year and battery capacity). The 23 models with data include 20 out of the 23 most common xEV models and covers 80% of the total stock of xEVs. As there are sometimes significant variations in battery size within one model, we defined the minimum and maximum values (e.g. for Tesla Model S ranging from 530 to 625 kg).

Data on cell mass is scarcer, and we only found information for three specific models: Tesla Model S, Nissan Leaf and Kia Soul EV. In addition, we found data on average cell mass as a fraction of battery pack mass from the GREET model (Dai et al., 2018).

These “primary” data on battery mass, cell mass and battery type for individual models served as the basis for the datasets used in each of the four classification systems. In the most detailed classification (O2), the data correspond one-to-one to the vehicle classes.

In all other classification systems (PS1, PS2 and O1), each vehicle class includes several models. In these classification systems, we defined the lower and upper limit of battery mass as the lowest and highest battery mass found for vehicles within each class.

Since we did not have data for all individual vehicle models in the O2 classification, we made assumptions about the battery pack mass for the remaining models in the following way: based on models with known battery pack mass and known vehicle mass we calculated a minimum and maximum share of total vehicle mass comprised by the battery. This was done individually for BEV, PHEV and HEV.

In the following we present results from the case study. Figure 2 shows the distribution of vehicles in the stock among different categories of mass, engine size and fuel type, according to the classification used in ProSUM. As seen in the top panels, the upper mass category (>1500 kg) spans a very large range of cars, since vehicle masses up to around 2500 kg are now common. For engine size (second panel line from the top), the middle category (1400-2000 kg) lies close to the middle of the range of actual engine sizes. However, the number of cars in this category is larger than the number of cars in all other categories combined. Both results indicate that an adjustment of the boundaries of the categories, and/or addition of new categories, might be appropriate. The lower panel shows that diesel and petrol (with no electric motor) are still clearly the most common fuel types. However, BEVs now comprise 6.6 % of the stock, PHEVs 3.3 % and HEVs 3.8 %.

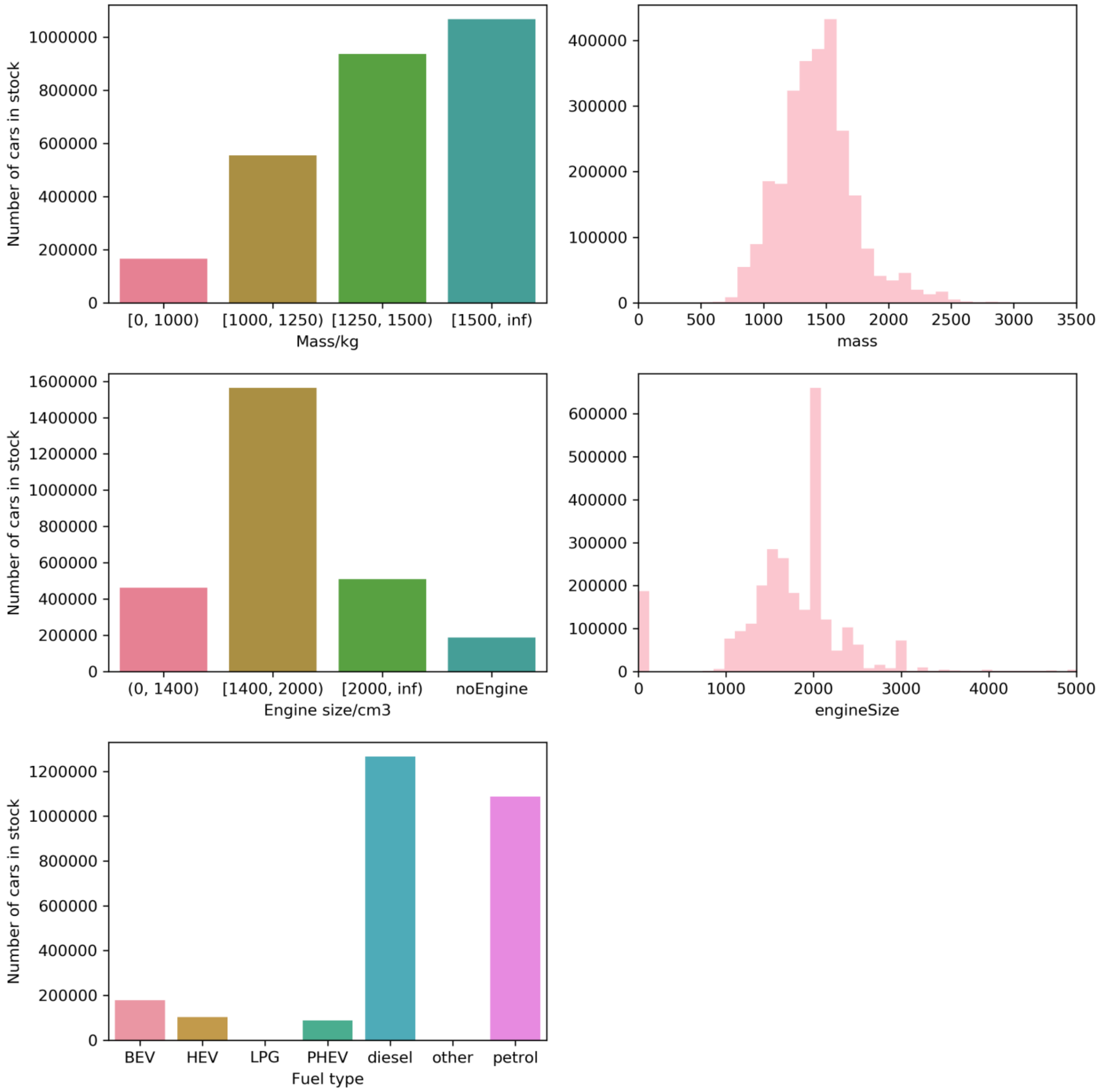

Figure 2 Distribution of entire passenger cars in stock in Norway per 30.9.2018, by mass, engine size and fuel type. The left panels show the categories used in the ProSUM vehicle classification, which are the same as the ones used by Eurostat. The right panels show histograms with higher resolution for mass and engine size.

Figure 3 shows the mass distribution of BEVs, PHEVs and HEVs in the stock. The red broken lines indicate the boundaries of the ProSUM/Eurostat vehicle classification categories. For BEVs, a substantial number of cars belong to each of the mass categories except the lowest one (< 1000 kg), which is almost empty. However, the upper category spans a very large range of vehicle masses, and includes very different models such as all the Tesla models (above 2000 kg) as well as most of the VW e-Golf vehicles (just above 1500 kg). For PHEVs, the classification provides almost no additional information, since around 99% of the PHEVs have a mass above 1500 kg. For HEVs, all categories except the lowest category contain a substantial number of cars.

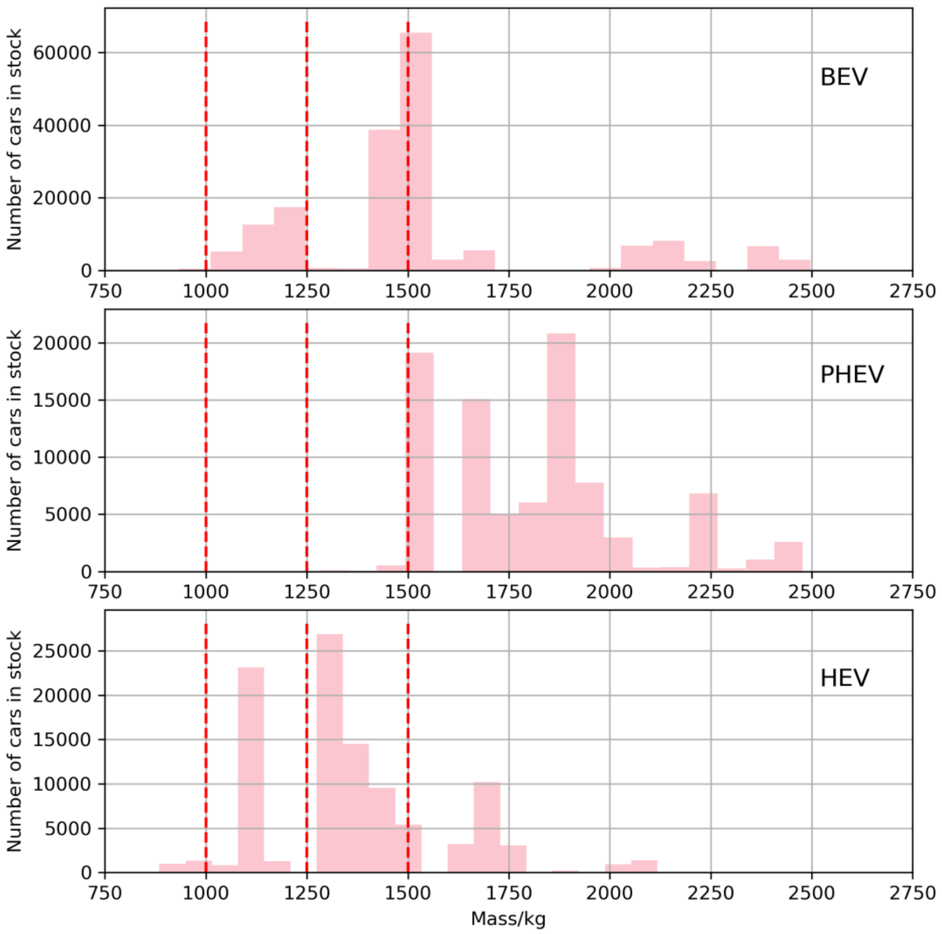

Figure 3 Mass distributions for BEVs, PHEVs and HEVs in stock in Norway per 30.9.2018. The red vertical lines show the boundaries between mass categories in the ProSUM and Eurostat classification systems.

Clearly, the classification would be more useful if it could better separate the heavier cars. The easiest solution would be to add new categories at the same intervals, i.e. with new boundaries at 1750 kg, 2000 kg, 2250 kg and perhaps 2500 kg. Alternatively, if there is a reason to keep the number of categories small, they should be shifted towards higher masses, e.g. with boundaries at 1200 kg, 1600 kg and 2000 kg instead. The former approach is probably preferred as new data would retain backward compatibility with the older classification system.

In the following, we present the results of the calculations, showing the in-use stock of xEV battery cells in Norway as of 30.9.2018.

Figure 4 shows the in-use stock of Li-ion (left) and NiMH (right) battery cells, calculated using the four different vehicle classification systems. The classification systems are depicted in decreasing degree of aggregation from left to right. As is clearly visible from the size of the boxes, the uncertainty of the estimate is substantially improved by using a more detailed classification. Current European vehicle statistics (Eurostat) is compatible with classification PS2 (however, the data are not publicly available in this resolution). By expanding the classification with new mass categories (O1), we see a substantial improvement in uncertainty for Li-ion batteries and a marginal improvement for NiMH batteries. The detailed brand-model-fueltype classification (O2) leads to an estimate with very low uncertainty.

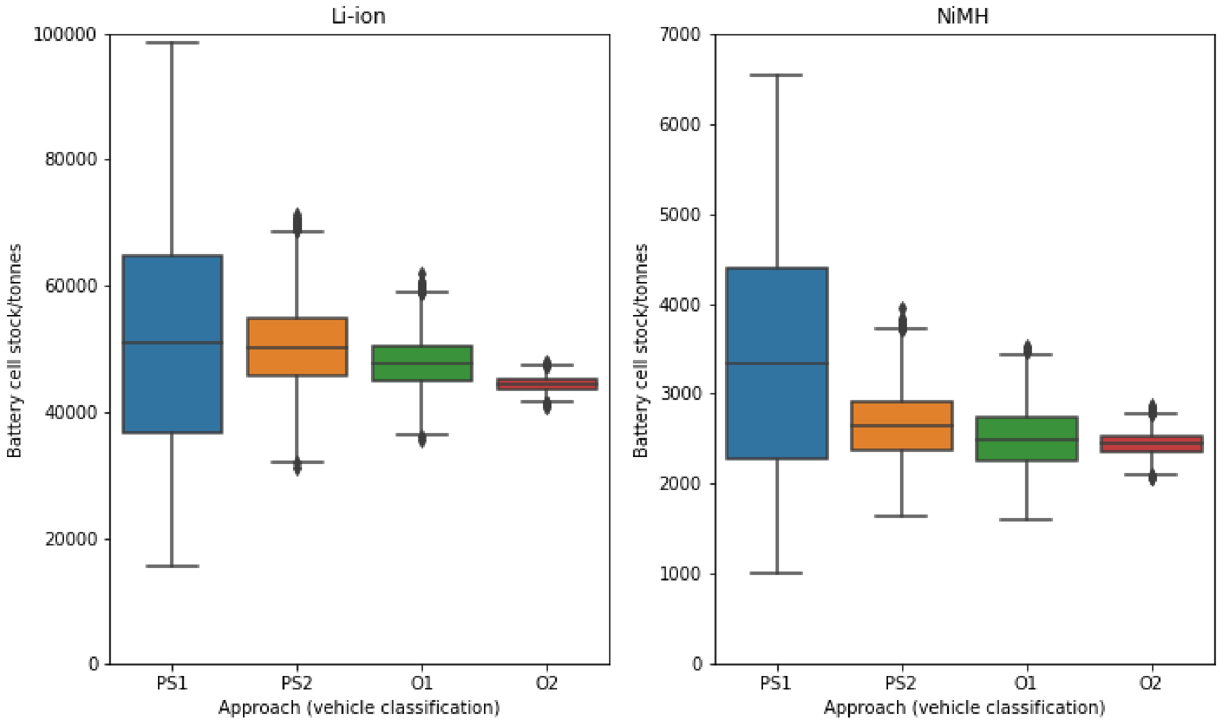

Figure 4 In-use stock of xEV battery cells on 30.9.2018, calculated using four different approaches. Left panel: Li-ion batteries. Right panel: NiMH batteries. Boxes include the 25th to the 75th percentile, the median is shown as the horizontal line within the box, and the whiskers show the lowest and highest datum still within 1.5 times the interquartile range from the median. Outliers are shown as diamonds outside the whiskers.

In Figure 5 we show the estimated stock of battery cells in BEV, PHEV and HEV separately. In the middle panel (PHEV) it can be seen that the PS2 provides very little improvement over the simplest classification (PS1) as nearly all PHEVs belong to the same mass category (> 1500 kg). The estimate is improved substantially by adding more mass categories (O1). As NiMH batteries are only used in HEVs, and most HEVs use NiMH batteries, the results for HEV are very similar to those for NiMH in Figure 4.

Using the O2 classification, we also obtained an estimate of the battery stock by battery chemistry, as shown in Figure 6.

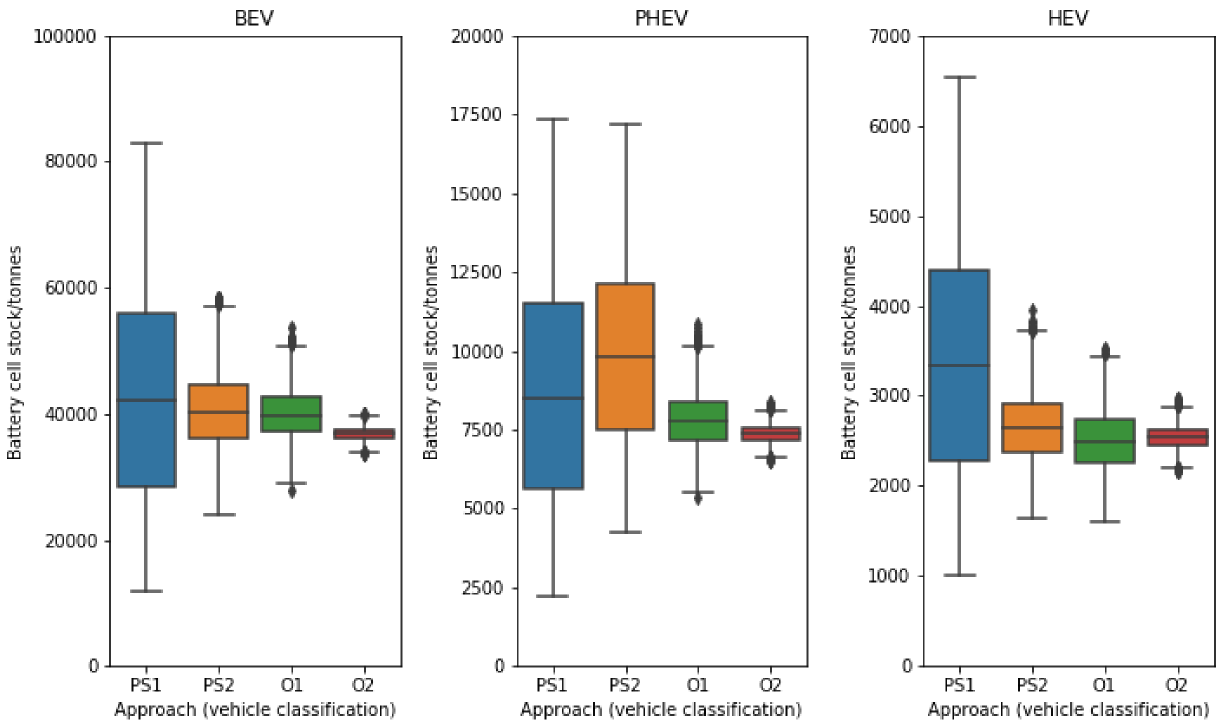

Figure 5 In-use stock of xEV battery cells on 30.9.2018, calculated using four different approaches. Left panel: BEV. Middle panel: PHEV. Right panel: HEV. Boxes include the 25th to the 75th percentile, the median is shown as the horizontal line within the box, and the whiskers show the lowest and highest datum still within 1.5 times the interquartile range from the median. Outliers are shown as diamonds outside the whiskers.

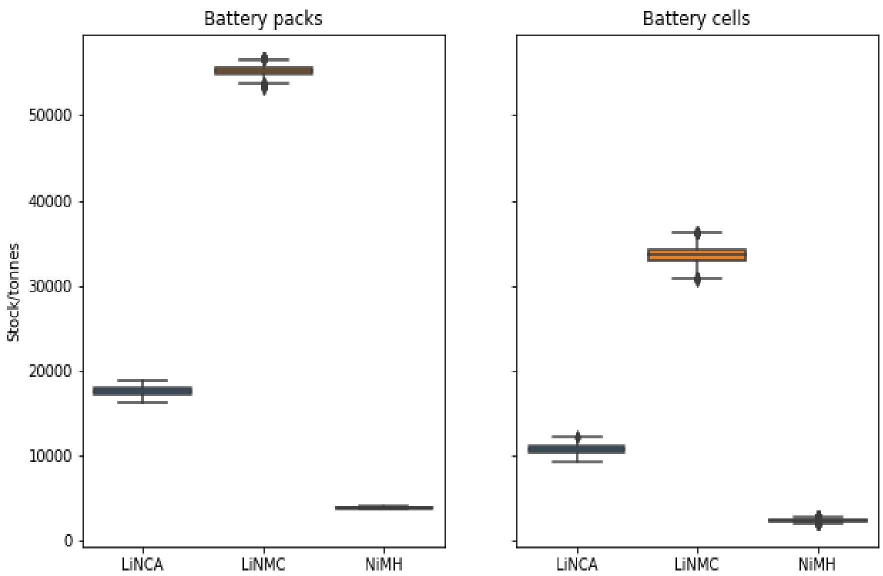

Figure 6 Battery stock by battery chemistry, estimated using O2 (brand-model-fueltype) classification. Boxes include the 25th to the 75th percentile, the median is shown as the horizontal line within the box, and the whiskers show the lowest and highest datum still within 1.5 times the interquartile range from the median. Outliers are shown as diamonds outside the whiskers.

The results of the case study have illustrated the importance of the vehicle classification system for estimates of raw material content in vehicle stocks and flows. We have shown that the current classification system used by Eurostat does not provide a sufficient distinction between different categories of xEV to allow for an accurate estimate of the battery stock. This is mainly due to the fact that a very large number of cars are within the very wide category with vehicle mass above 1500 kg. The statistics can be improved by expanding the classification with additional mass categories in 250 kg intervals, up to 2500 kg. This will lead to an improved estimate, especially for PHEV. As the data collected from Eurostat necessarily originate from the national vehicle registries in which detailed information about the mass of vehicles is recorded, it should be very feasible to introduce this revision to the reporting of data from Member States to Eurostat. A much better estimate of battery stocks and flows would be possible if Member States reported data at the level of the O2 classification. However, we consider this to be much less feasible, as it would require harmonization of brand names, model names etc. between different countries, since there may be differences in spelling.

In addition to an expansion of the mass categories, we recommend introducing reporting of vehicle power, either as a replacement for engine size or in addition to it. A more accurate estimate of battery stocks would be enabled if battery capacity or battery mass were reported in addition to existing data, i.e. including this as a new attribute in the classification as well. Information on battery mass or capacity is, to our knowledge, currently not recorded in the national vehicle registry. According to Opplysningsrådet for Veitrafikken (OFV), who supplied the data on the Norwegian car stock, they are currently working to include power as an attribute in their database. However, sample data shows that the primary data from the central vehicle registry is often incorrect.

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