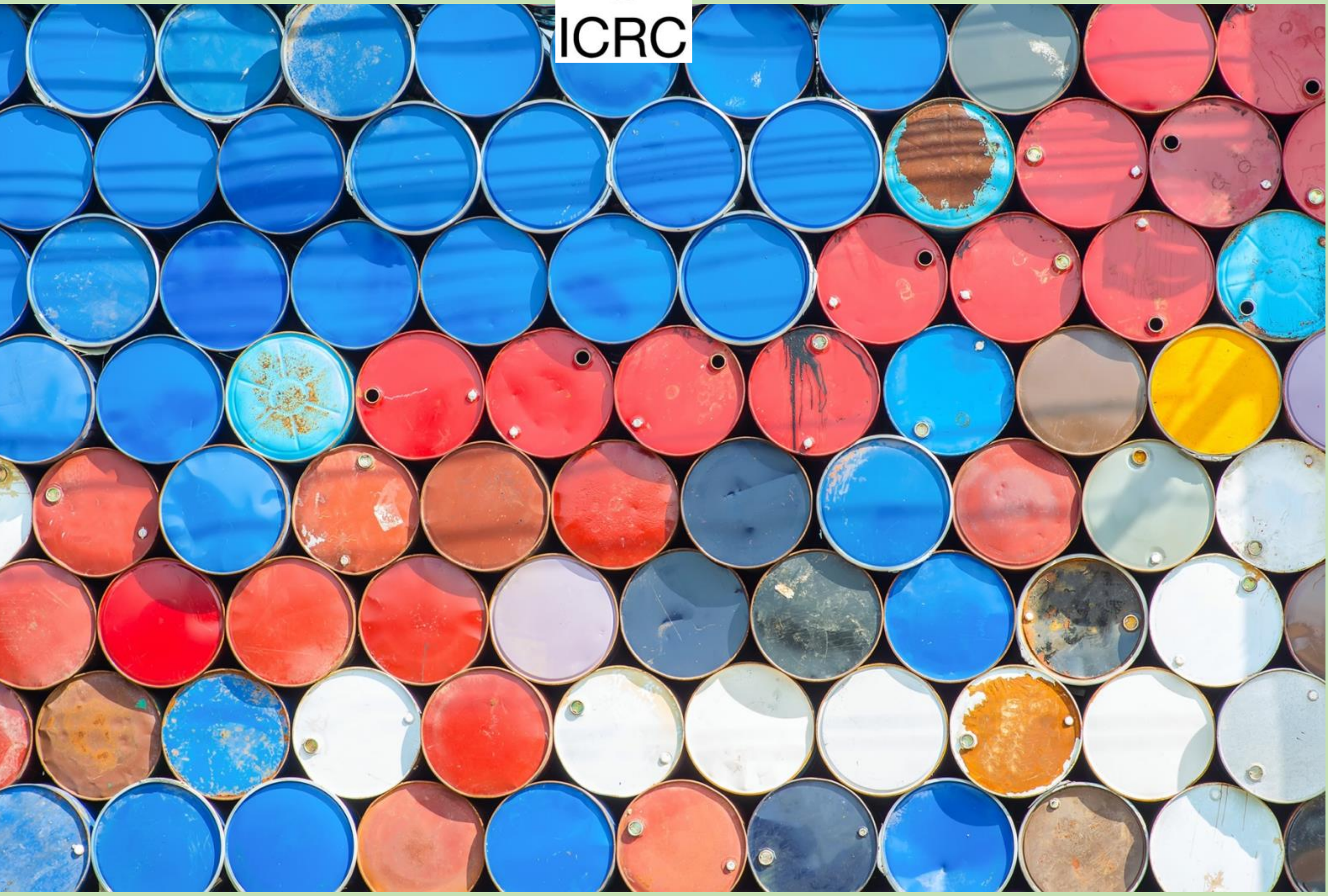

Sustainable Management of ICRC's Garage Waste

November 2021

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DEPARTMENT OF CIVIL AND
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AWARE
Assessment on WAste
and REsources

Research Group AWARE - *Assessment on WAste and REsources*

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CHAPTER 1

Introduction

Garage waste in the humanitarian context

Managing garage waste is a critical problem in fragile contexts such as underdeveloped countries or regions with humanitarian circumstances. These countries usually lack the basic waste management infrastructure to deal with garage waste appropriately. The problem is compounded by weak environmental legislation and poor implementation of the legislation. Waste management can easily become the least of concerns in a dire humanitarian situation. A report by PAX shows toxic used oil flowing in Syria, referred to as *The River of Death*. Thousands of barrels of used oil were found flowing into canals and creeks and ending up in a 160 km long river generated by the activities of local industries, which has been neglected due to fragile situations in Syria.

Figure: Contamination of natural environment and rivers by used oil in northeast Syria known as the *River of Death*

At ICRC, a study conducted in 2018 in collaboration with academia compared different categories of waste generated by ICRC including essential household items, e-waste, and packaging, among others. The study identified garage waste as one of the critical waste categories.

This report presents the results of the study conducted in 2020-2021 on ICRC's garage waste. The overall goal of the study is mainstreaming environmental sustainability for ICRC's garage waste. The project seeks the following objectives in specific:

- Assessing the environmental impact of ICRC garage waste through application of scientific methods

- Identifying waste management practices with the highest environmental impact

- Proposes recommendations and mitigation actions to ICRC to deal with each type of garage waste

These recommendations will be used to develop standard operating procedures (SOPs) to be implemented in the field by ICRC staff. The results can be of use for other humanitarian organizations with similar operating contexts as of ICRC.

The next chapter, chapter 2, prioritizes ICRC's waste items to identify the top-priority waste that require urgent attention, known as *the critical few* based on two criteria: volume of the waste and hazardousness. Used oil was found to be the highest-priority type of waste by far. Batteries, AC refrigerants, and oil filters were found to be the next important waste items, respectively.

Chapter 3 introduces the methodology of the study. Several methods and techniques were used throughout the study. However, life cycle assessment (LCA) is the backbone methodology of this report, which is explained in the chapter. LCA is applied to assess the environmental impact of each waste item. The results are provided for different mid-point and end-point impact categories. Based on the results, recommendations for waste management and disposal are provided.

Chapters 4-9 provide the results of environmental analysis for used oil, used oil filters, used lead-acid batteries, AC refrigerant, used tires, and used glass, respectively. Each chapter starts with an environmental analysis, based on LCA, for a specific waste item. The results of the analysis are then translated into pragmatic recommendations, ranked based on their environmental favorability. A traffic light system (green, amber, and red) is introduced to recommend a ranked list of waste management options and the implementation considerations for each type of waste. Quality, safety, and environmental (QSE) questions are provided, where applicable.

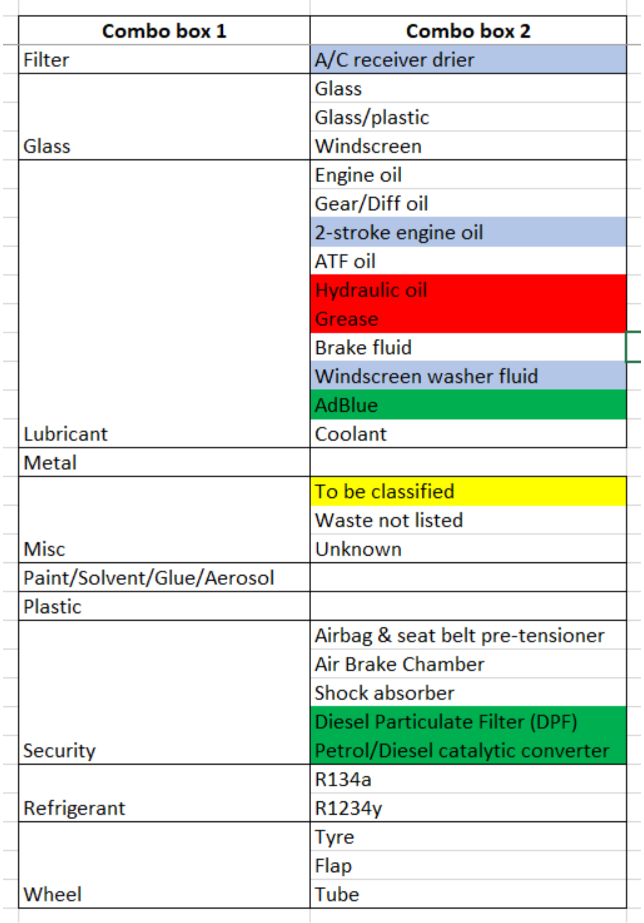
Finally, chapter 10 provides general insight on how ICRC should make sound decisions on waste management for the waste items not included in this study. Circular economy and EU Waste Framework Directive are used to guide the decision making.

CHAPTER 2

Prioritization of ICRC’s Garage Waste

1. What are the waste items considered in this study?

Waste items were selected from the combo box. The combo box is developed by ICRC logistics department and classifies ICRC garage waste into different categories. It is shown in the following figure. To achieve an accurate ranking, undefined waste items such as the category “Misc.” including “to be classified”, “waste not listed”, and “unknown” were removed from the analysis as it is not possible to analyze the importance and hazardousness of these items. Moreover, when the items within a category (combo box 1) were substantially different in terms of specification and characteristics (such as “shock absorber” and “petrol/diesel catalytic converter” which are both classified in the category “security”), the items were separately considered for the analysis, as they generate different environmental impact and should be treated separately.



Combo box 1	Combo box 2
Filter	A/C receiver drier
Glass	Glass
	Glass/plastic
	Windscreen
Lubricant	Engine oil
	Gear/Diff oil
	2-stroke engine oil
	ATF oil
	Hydraulic oil
	Grease
	Brake fluid
	Windscreen washer fluid
	AdBlue
	Coolant
Metal	
Misc	To be classified
	Waste not listed
	Unknown
Paint/Solvent/Glue/Aerosol	
Plastic	
Security	Airbag & seat belt pre-tensioner
	Air Brake Chamber
	Shock absorber
	Diesel Particulate Filter (DPF)
	Petrol/Diesel catalytic converter
Refrigerant	R134a
	R1234y
Wheel	Tyre
	Flap
	Tube

Figure: Classification of ICRC garage waste in combo boxes

2. Adopting criteria for ranking

The purpose of this analysis is to rank waste items and select the top-priority waste items known as *critical few*. "Criticality" was defined under two criteria: 1) volume of waste item at ICRC garages and 2) hazardousness. This means a waste item that is generated in high volumes at ICRC garages and at the same time is considered to be hazardous should be ranked higher and receive urgent attention.

2.1. Criterion 1: Volume of waste items

The spreadsheet "ICRC Spare Parts Waste Report 2018_2020" was used to ascertain the volumes of waste items. This document has been developed by the ICRC delegation in Kenya and includes the volume and financial value for all the items wasted in ICRC garages globally between 2018 and 2020. The spreadsheet classifies garage waste into 14 categories. The categories, their quantity, and financial value are presented in the following table.

Table: Waste streams, quantities, and financial value at ICRC delegation 2018-2020

Waste Stream	Qty. Issued	Value (CHF)
Lubricants	271,984	988,075.39
Filters	56,364	1,066,921.96
Body structure	41,493	1,122,436.21
General materials	35,731	366,733.34
Power unit engine	22,309	798,320.22
ICRC emblem	21,574	214,743.89
Suspension	20,295	352,765.73
Tires	17,388	2,510,340.67
Power transfer	16,898	430,457.53
Electric system	13,932	504,964.59
Brakes	13,568	560,381.72
Battery	5,042	515,632.14
Telecom	2,258	704,918.50
Tools	2,122	194,353.88
Grand Total	**540,960**	**10,331,045.77**

The quantity of waste items was selected over the financial value for analysis because it can be often the case that a lower-quality item that contains substandard or hazardous material has a low financial value, while it is actually an important item from environmental perspective. When an item of the combo box was not available as a waste stream, a search was made within all waste streams to find the quantities for that item. The following table shows the quantities of waste items in the combo box, extracted from the ICRC spreadsheet.

Table: Volume of waste items analyzed in this study

Waste item	Volume
Used oil	271,984
Oil filters	11,790
Tires, flaps & tubes	17,665
Batteries	5,042
Glass & windscreen	1,079
Ac refrigerant	95
Brake chamber & shock absorbers	359
Airbag & seatbelt	69
Diesel particulate filter	17
Ac receiver drier	7
Diesel catalytic converter	1

2.2. Criterion 2: Hazardousness

To delineate hazardousness, it was important that both practical and scientific views are taken into account. To gather the ideas of practitioners, a questionnaire was developed. The questionnaire measures the “perceived hazardousness” by field practitioners, meaning that based on their preferences, how hazardous each waste item would be. At the beginning of the questionnaire, the respondents were provided with explanations on the purpose of the data collection, and it was clarified that hazardousness in the context of this questionnaire is defined as “*How much do you think a specific garage waste would negatively impact the ecological environment?*” and “*How difficult you think it is to manage a specific garage waste?*”.

The questionnaire contained 14 questions. Questions 1-4 collected information about the respondent’s name (optional), the delegation they work in (optional), years of experience (mandatory), and level of education (mandatory). Next, questions 5-14 asked the respondent to rate each waste item on a standard five-point Likert scale, where 1 being the least perceived hazardous and 5 being the most. An illustration for each waste item was provided to help respondents with visualizing and deciding on the hazardousness.

The link of questionnaire was populated by the head of fleet management unit, Mr. Rohrbach Werner, amongst vehicle fleet managers in different countries. 8 responses were received from Africa, America, and Asia, representing a good coverage geographically. Equal weight was assigned to the preferences of respondents. Years of experience and level of education were not used to allocate different weighting, because the responses were mostly homogenous. This means a waste item is perceived to be hazardous or non-hazardous almost equally by all respondents. For example, the set of responses for “used oil” was {5, 5, 5, 5, 5, 4, 5, 5}, which means all the respondents are unanimous in considering the waste item as extremely hazardous. The responses are available in the following table.

Table: Perceived hazardousness of waste items by ICRC field practitioners

What is your name (optional)?	At which ICRC delegation do you work (optional)?	How many years of experience do you have in logistics (ICRC and outside)?	What is your level of education?	Batteries	AC refrigerant	Used oil & oil filters	AC receiver drier	Tires, flaps & tubes	Diesel particulate filter	Diesel catalytic converter	Airbag & seatbelt	Glass & windscreen	Brake chamber & shock absorbers
Anonymized	CO	More than 5 years	University degree	5	5	5	5	5	5	5	5	1	1
Anonymized	Myanmar	More than 5 years	High school and pre-university										
Anonymized	Bamako	3 to 5 years	High school and pre-university										
Anonymized	Moscow	More than 5 years	University degree										
Anonymized	Abuja	1 to 3 years	University degree										
Anonymized	Ethiopia	More than 5 years	University degree										
Anonymized	KIGALI	More than 5 years	University degree										
		More than 5 years	University degree										
			Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note: Since the results of this research will be submitted to an academic journal for publication, the numerical results are not shown in this table.

The results are available upon personal request from the principal investigator, Dr. Hossein Zarei.

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To incorporate scientific view of hazardousness in the analysis, the Official Journal of the European Union (2014) on the "*list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council*" was used. The document provides a list of hazardous waste and substances based on EU directives and legislations. Each waste item was searched within the document, and it was identified whether or not it is hazardous. The following table shows whether each waste item is found to be hazardous based on EU Directive together with the respective category in the EU Directive.

Table: Hazardousness of waste items based on the EU directive

Waste item	Hazardous?	Waste category as per EU directive
Used oil	Yes	Category 13: oil wastes and wastes of liquid fuels (except edible oils, and those in chapters 05, 12 and 19)
Oil filters	Yes	16 01 07: oil filters
Tires, flaps & tubes	No	16 01 03: end-of-life tires
Batteries	Yes	16 06 01: lead batteries
Glass & windscreen	No	16 01 19: plastic from end-of-life vehicles 16 01 20: glass from end-of-life vehicles
Ac refrigerant	Yes	14 06 01: chlorofluorocarbons, HCFC, HFC 16 05 04: gases in pressure containers (including halons) containing hazardous substances
Brake chamber & shock absorbers	No	16 01 06: end-of-life vehicles, containing neither liquids nor other hazardous components
Airbag & seatbelt	Yes	16 01 10: explosive components (for example airbags)
Diesel particulate filter	Yes	16 01 04: end-of-life vehicles 06 13 05: soot
Ac receiver drier	Yes	14 06 01: chlorofluorocarbons, HCFC, HFC
Diesel catalytic converter	No	16 08 01: spent catalysts containing gold, silver, rhenium, rhodium, palladium, iridium or platinum (except 16 08 07)

3. Results and analysis

Once the criteria were defined and data were collected, the data gathered under all the criteria should be aggregated to achieve the final ranking. Since the data about volume (criterion 1) and hazardousness (criterion 2) have different units and scope, they were normalized prior to aggregation. When dealing with datasets of different nature, normalization removes the unit of data as well as variability in the scope and reproduces data in the range 0 to 1, while keeping the original essence of each data point. This allows different datasets to be weighted and aggregated.

After the normalization was performed, the data were aggregated. A weighting system was used for aggregation. 50% of the weight was given to volume (criterion 1) and 50% to hazardousness (criterion 2). Of the latter, 40% was assigned to perceived hazardousness by respondents (obtained through questionnaire) and 10% to the waste items which were found to be hazardous based on the EU directive. Accordingly, the final ranking was generated. A sensitivity analysis was conducted, and the allocated weights to each criterion were changed ±10. The overall ranking did not change as the result of change, suggesting that the ranking is robust. The result of the final ranking is shown in the following figure.

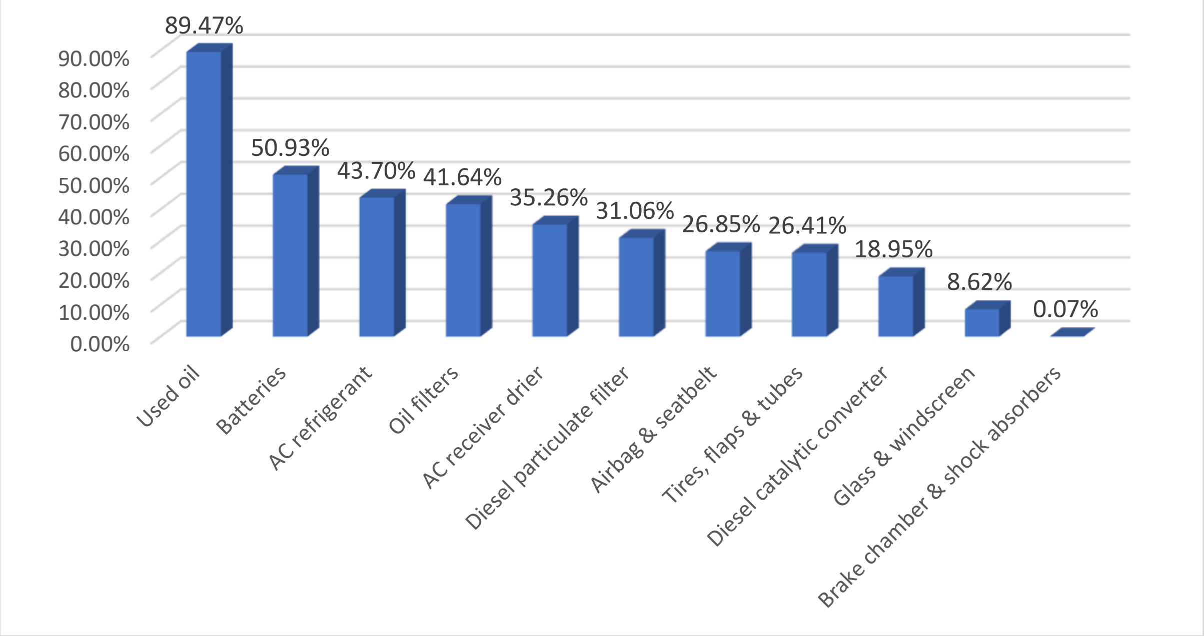

Figure: Final ranking of waste items

Based on the ranking, **used oil** was found to be the most *critical* waste item by far, weighed nearly 90%. This emphasizes that used oil requires urgent attention in ICRC garages as it is both significant in terms of volume and at the same time hazardous both from practical and scientific perspectives.

The second most *critical* waste is **batteries**. The volume of used batteries is less overall as compared to used oil but still high enough to be counted as a critical waste. It is also a hazardous waste from practical and scientific perspectives and leakage of used lead-acid batteries stored in garages can have significant environmental and health consequences.

AC refrigerants and **oil filters** were ranked almost the same as the third *critical* waste items. Both of these items are hazardous, however, in terms of volume, AC refrigerant is considerably less than oil filters. Only 95 AC refrigerants were wasted in all ICRC garages between 2018 to 2020, as compared to 11,790 oil filters in the same period. A discussion was held with Fleet Forum and ICRC HQ Logistics team (in an online meeting on 2 July 2021), and it was decided that oil filters are taken for further analysis. Despite being hazardous, AC refrigerants were disregarded as a critical waste item, due to negligible overall amount wasted in all ICRC garages.

Finally, an interesting observation in the ranking is tires being ranked as 8th recognized as being only 26.41%. critical. The reason is although tires are wasted in high amounts in ICRC garages, they were not ranked as hazardous by respondents nor by EU directive. This finding is supported by the results of the previous survey about ICRC garage waste. 69 delegations participated in that survey and tires were among the few waste items that the respondents asserted were managed properly and given to certified waste recycling companies or re-treaded and reused by local population. This advocates that tires should not be classified as *critical* waste.

The prioritization provided a ranking of ICRC garage waste items based on an academically robust methodology and concludes that **used oil**, **batteries**, and **oil filters** are the *critical few* waste items which require further environmental analysis. Field managers should be provided with clear guidelines and training about dealing with these *critical few*, as improper waste disposal and handling of waste items can lead to serious negative consequences.

Finally, in addition to identifying used oil, batteries, and oil filters as the *critical few*, the results of ranking can be useful to ascertain the level of criticality for other waste items. For example, going beyond the *critical few*, the ranking suggests that further resources and attention should be directed to items such as tires or airbags, rather than glass and windscreen, as they are prioritized as more critical waste items. Moreover, the ranking can be conveniently updated in the developed spreadsheet, should the volume of waste items change in future.

CHAPTER 3

Methodology

1. An overview of life cycle assessment (LCA)

Life Cycle Assessment (LCA) is a quantitative methodology to assess the potential environmental impacts and resources used throughout the life cycle of any system (i.e., product, service, etc..). The first examples of LCA studies were conducted around 1970 in USA, under the name of Resource and Environmental Profile Analysis (REPA) which was developed by the U.S Environmental Protection Agency (EPA). Later In the 1990s, the Society of Environmental Toxicology and Chemistry (SETAC) played a great role in developing the LCA methodology as we know it today. Klöpffer (1997, 2006) discussed the efforts made by SETAC to develop a code of practice for LCA and taking the first steps toward the standardization of the method.

According to SETAC, LCA is defined as "*Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal*" (The Society of Environmental Toxicology and Chemistry, 1993).

Based on SETAC initiative for LCA standardization, the methodology was refined and standardized by the International Organization for Standardization (ISO) in a series of documents from ISO 14040 to 14047 where the most relevant are ISO 14040 (2006) for principles and framework and ISO 14044 (2020) for requirement and guidelines. The objective of LCA is defined by ISO as a tool to address the environmental aspects and potential environmental impacts (e.g., use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e., cradle-to-grave) (ISO 14040); where the word "product" refers to products systems and service systems.

The LCA as a tool was also adopted by the European Commission as the best framework for assessing the potential environmental impacts of products currently available. Hence, the commission released the European platform for LCA, and its joint research center in collaboration with the institute for environment and sustainability issued the International Reference Life Cycle Data System (ILCD) Handbook (JRC-IES, 2010) as a general guide for life cycle assessment in line with ISO 14040 and 14044. After the publication of ILCD, the European Commission issued the Product Environmental Footprint Guide (PEF) (EC-JRC, 2012) as a refined brief version derived from ILCD aimed at people who have limited knowledge of LCA, hence it is written in a more accessible manner.

2. LCA structure and phases

An LCA study consists of four phases, and it is an iterative methodology, this means that any step can be revised many times during the study is prepared if a need for that emerges. This iterative flexible approach within each phase and between phases contributes to the comprehensiveness and consistency of the study and the reported results. In the following figure, the four steps are illustrated connected by a double-headed arrow representing the iterative nature of the methodology. In the following sections, each phase of the LCA is described briefly in accordance with ISO 14040 (2006), ISO 14044 (2020), ILCD (2010), and PEF (2012).

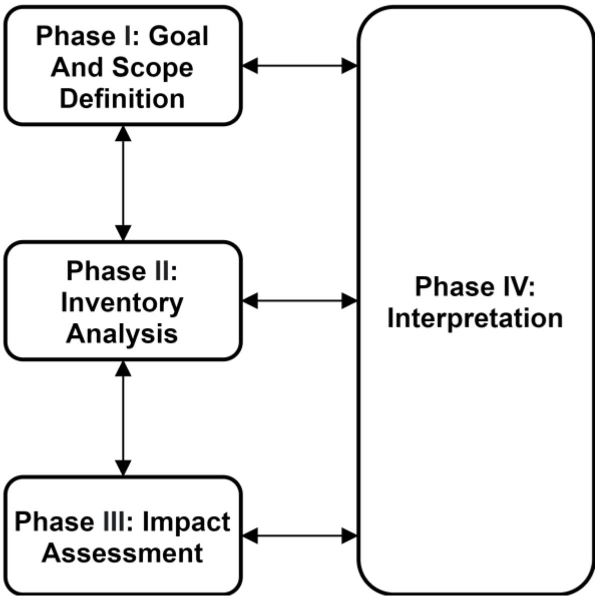

Figure: LCA phases. (ISO, 2006)

2.1. Phase one: goal and scope definition

It is the first phase of any LCA study in which many starting points and parameters are set (e.g., goal of the study, functional unit, system boundary…etc.). Goal and scope in LCA are not synonyms, as each word identify different aspects and answer different questions related to the study.

2.1.1. Goal definition

The goal definition answers the question of "why are we carrying out the LCA study?", as it involves the statement of the intended application of the study, the reasons that the study is been carried out for, the intended audience and way how the results will be dealt with, for example, whether it will be used in comparative assertions to be disclosed to the public.

It is very important to define the reasons for carrying out the LCA (e.g., is it to compare two systems and choose the best among them? Or a system is studied to identify an environmentally weak point in the life cycle). Usually, an LCA is required in three main situations:

1) The LCA results will be used to support a decision on the analyzed system but the changes that this decision will imply are minor on a small scale (e.g., modifying a machine in a factory).

2) The LCA results will be used to support a decision on the analyzed system and the decision involves big major changes in the system (e.g., constructing a new factory).

3) The LCA results will not be used for decision making but only for research and monitoring reasons.

Each situation imposes different modeling approaches of the system and other choices to be made throughout the study. Hence the context and final aim of the study must be well known and identified before starting.

2.1.2. Scope definition

While the goal is to answer the question of "why", the scope definition stage is addressing the question of "What are going to be studied in the LCA?". In this phase many important elements shall be defined including, the system which will be studied in detail along with its function, the functional unit chosen for the system, the system boundary, the procedures to solve the cases of multifunctionality issues that might arise, in addition to life cycle impact assessment methodology and impact categories which is relevant to phase three of LCA, plus the level of data quality required for the study.

The system boundary determines which unit processes of the system will be included in the analysis. According to the goal of the study defined in the previous stage, the convenient system boundary shall be chosen. By definition, a life cycle assessment should include the entire life cycle of a product or a service which in this case is referred to as "cradle to grave" or "cradle to cradle" in case a recovery process is concluding the system. However, other system boundaries can be applied such as "cradle to gate" which starts from raw materials acquisition and ends with the manufacturing of the product, also the end-of-life analysis which focuses on what happens after the usage of the item.

The functional unit represents the quantified form of the identified function of the studied system to be used as a reference unit. It is essential for the functional unit to be clear and measurable as it will be the reference value to which the input and output of the system are normalized mathematically. After a functional unit is defined properly, a reference flow can be figured out to satisfy this functional unit. For instance, in a shirt life cycle, the function of the system is the production of shirts and functional unit is one shirt of a specific size that can be worn once per week and endure washing cycles of 30 degrees Celsius over a span of three years of usage, and the reference flow can be the amount of cotton needed to produce such shirt. If systems are to be compared, they must have the same function quantified by the same functional unit, represented each by its reference flow. In the example of the shirt, a system which produces a shirt with the same properties using linen can be compared, with a reference flow of amount of linen required for production.

Data quality requirements should be decided to allow the goal and scope of the LCA to be met successfully. Data quality requirement tackles the properties of data collected for the study, for instance, time and geographical coverage which means age and time span of collected data, and the geographical area where the data will be collected from. In addition to precision, completeness, representativeness, and consistency of data collected.

A problem of the so-called multifunctionality can arise when the system analyzed has more than one function. The focus of LCA is often on one specific function of a system. For instance, in multi output systems like refineries of crude oil, many different products come out of such system, however the interest of an LCA study is the life cycle of one product (e.g., Benzine) while the other co-products (e.g., diesel, fuel oil, kerosene, etc.) are out of scope. The system can also be multi-input system like waste treatment processes, which has the main function of treating waste, but it can also recover energy. Moreover, the same issue of multifunctionality can emerge in cascaded systems like recycling.

According to ISO standards, there is hierarchy of options to deal with multifunctionality:

a) Step 1: wherever possible, the multifunctionality should be avoided by:
    1. Dividing the unit process where the problem emerges from into two or more sub-processes and collecting the input and output data related to these sub-processes.
    2. Expanding the products system (i.e., system boundary) to include the additional functions related to the co-products. For example, if a system produces two products A and B, and the interest is only on the impacts associated with the life cycle of product A, it is possible to expand the system boundary by including a conventional process or technology which produces product B, but with a negative sign. A negative sign states the fact that the amount of product B produced from the system under study helps to avoid its production from a conventional process, therefore it is a “credit” for the system as it avoids the environmental impact of the production of co-product B from conventional process. An example on this case can be producing heat in a co-generation plant substituting heat production from oil, so the avoided impact of the substituted process (i.e., heat from oil) will be subtracted from the total impact of the cogeneration plant.

b) Step 2: Allocation or partitioning of input and output flows based on physical relationships between different functions or products of the system. For example, mass quantities, if products A weighs more than co-product B, more impact will be allocated to product A.
c) Step 3: Allocation or portioning of input and output flows based on non-physical relationships between different functions or products, this happens in case physical relationship cannot be identified or used. Other relationships can be developed to be used like economic values, if product A has higher economic value (i.e., market value per unit mass*mass produced) than co-product B, more impact will be allocated to product A.

Allocation in general should be avoided as far as possible, as it usually does not reflect the reality. For instance, products A with higher economic value is not necessarily responsible for the major part of impacts of the whole system studied. For this reason, the ISO standards proposed this hierarchy to follow in order to obtain the most realistic and accurate results from an LCA.

2.2. Phase two: Life Cycle Inventory Analysis (LCI)

The aim of this phase is to quantify all the input and output flows associated with the different steps of the life cycle of the product. ISO 14040 (2006) identifies this phase as follows “phase of life cycle assessment involving the compilation and quantification of inputs and output for a product throughout its life cycle”. The input and output flows shall be eventually referenced to the functional unit of the system. Given that LCA is a linear algebraic methodology (Matthews, Hendrickson and Matthews, 2014), all flows and associated impact can be referenced at a later stage to a different amount if needed with a simple linear multiplication.

In the LCA modeling terminology each step of the life cycle of a product or service is expressed as “unit process” (figure below) where the types of input and outputs flows are usually categorized under major categories such as energy inputs, raw material inputs, or other environmental quantities like land use, in addition to output flows which are most likely to be products, co-products or waste, plus the emissions to air, water and soil.

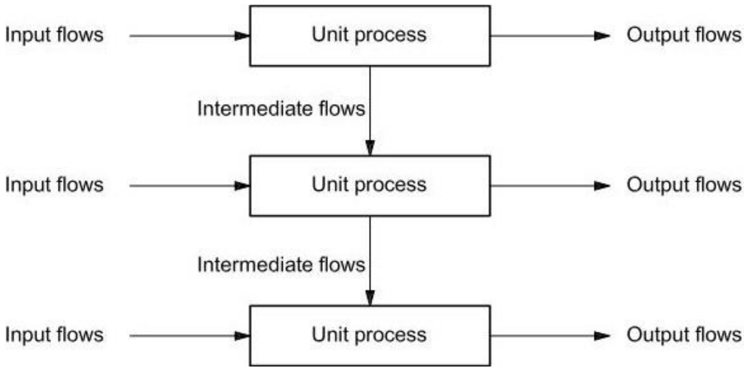

Figure: Example of a set of unit processes within a product system. (ISO 14040)

By the end of this process, a full environmental inventory for the system studied should be obtained representing the amounts of material and energy consumption, of emissions, of waste and all the types of flows mentioned previously.

Data collection for inventory fulfillment is an iterative process which is carried out following data collection requirement in phase one of the LCA. In other words, while the data is collected and the system is known more, some limitations or new requirements for data might arise which implies a change in how the data is collected for example. In some cases, going back to phase one of goal and scope definition and revising it can be an option if some issues in data collection emerges that derail the progress of the study or prevent the goal of the study to be met. This is an example of the iterative nature of LCA.

Data can be classified into three ranks depending on the way how it is acquired:

- Primary data: obtained from direct surveys. Usually, the data related to the foreground processes (i.e., unit processes of the main system studied) is acquired in this way.

- Secondary data: obtained from literature and databases of LCA modeling software. Usually used for background processes which serve the foreground system processes (e.g., domestic electricity mix used in foreground production phase).

- Tertiary data: gathered from average values and estimations.

Primary data collection is the most preferred overall, as it reduces the uncertainty of data besides it represents the system under study in a more realistic specific way. Secondary data collection from databases is accepted also as it makes the collection of data less complex and faster, however the trustworthy of databases or literature where the data is derived from has to be reviewed.

2.3. Phase three: Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment is the third phase of LCA, and the complementing step of the inventory analysis carried before, it can be defined as “The impact assessment phase of LCA is aimed at evaluating the significance of potential environmental impacts using the LCI results. In general, this process involves associating inventory data with specific environmental impact categories and category indicators, thereby attempting to understand these impacts. The LCIA phase also provides information for the life cycle interpretation phase.” (ISO 14040, 2006).

LCIA has to be carried out following a sequence of steps: three mandatory steps that must be carried out to achieve the LCIA results, in addition to three following optional steps (figure below).

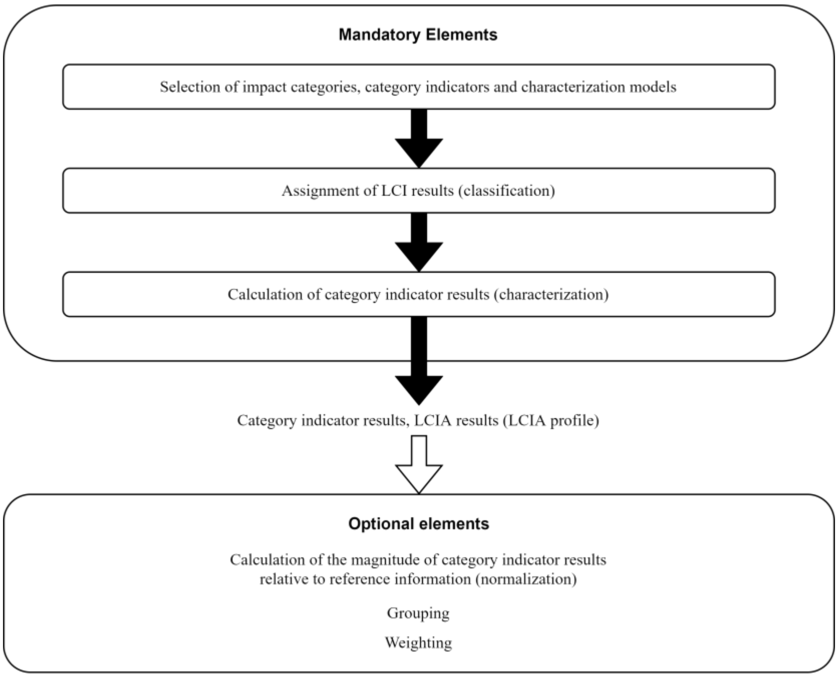

Figure: Elements of the LCIA phase. (ISO 14040)

Selection of impact categories, indicators and characterization models is the starting point. This step has to be consistent with the goal and scope of the study. Each impact category represents a specific environmental issue of concern to which life cycle inventory analysis results (i.e., flows) may be assigned to. The impact categories can either be related to input flows (e.g., materials and resources consumption) or output flows (e.g., emissions to water, air and soil).

When choosing the impact categories to be considered in a specific study, an impact indicator for each impact category must be chosen depending on where it is located in the environmental mechanism. An impact indicator is a quantifiable representation of an impact category.

An environmental mechanism is all the real environmental processes related to the characterization of the impact, while characterization models are models developed by scientists after studying each environmental phenomenon to find the relation between the LCI results and category indicators whether the indicators fall in middle point or end point in the environmental mechanism domain. From characterization models, characterization factors can be derived which are the factors applied to convert an assigned LCI analysis result to the common unit of the category indicator. Figure below represents an example for climate change impact category explaining the terms mentioned previously.

Classification is the second mandatory step which involves the assignment of the inventory results to the selected environmental impact categories (e.g., CO_2 emissions is assigned to climate change impact category). It is also normal that one flow is assigned to more than one impact category.

In characterization step LCI results are converted into common units using characterization factors from chosen characterization models, then the converted amounts (all with the same unit) are aggregated to one number within the same impact category, after aggregation the indicator result is obtained. A simple example for climate change category following GWP 100 model of Intergovernmental Panel of Climate Change (IPCC) is showed in table below.

Table: A characterization example for climate change impact category. (Houghton, Jenkins and Ephraums, 1992)

Flow	**GWP 100 Characterization Factor (kg CO_2 eq.kg^{-1})**
Fossil CO_2	1
CH_4	25
NO_2	298

If 5 kg of CO_2, 7 kg of CH_4 and 3 kg of NO_2 are emitted per functional unit (FU), the aggregation will follow this equation:

$5*1 + 7*25 + 3*298 = 1074$ kgCO_2 eq. / FU

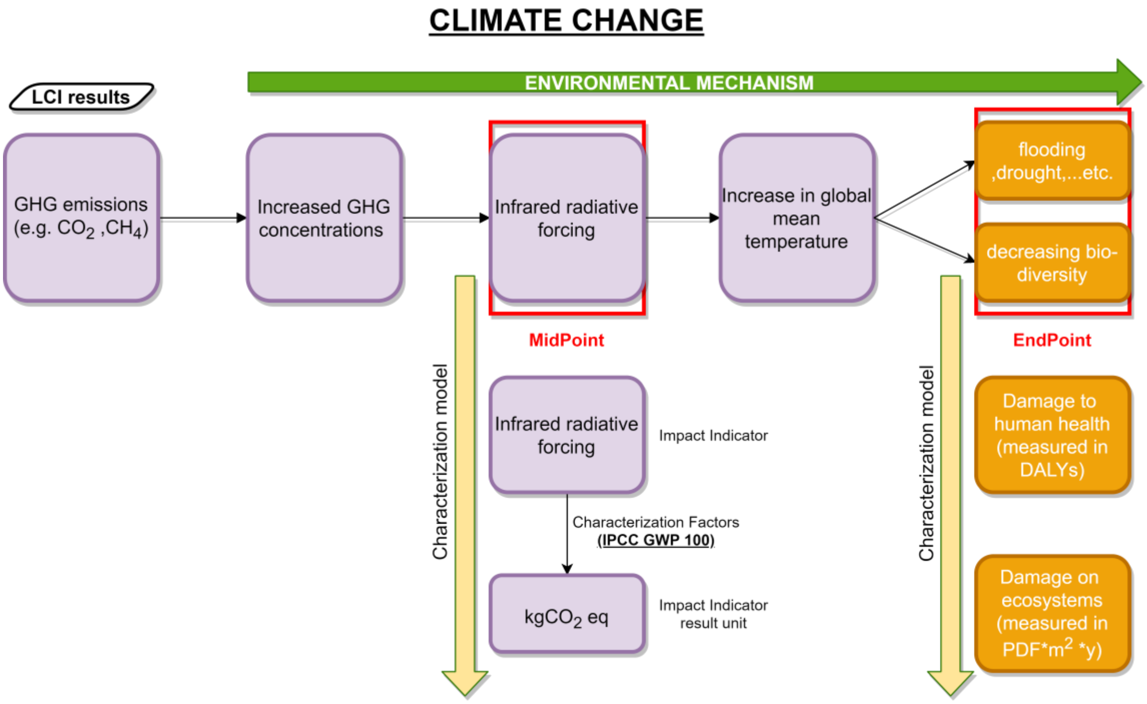

Figure: An example for midpoint and endpoint characterization.

Normalization is the first optional step that can be applied in LCIA phase. It is the calculation of the magnitude of the category indicator results relative to some reference information or values. ISO 14044 recommends that the selection of the reference system should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value. The reference information for normalization is therefore based on the annual global emissions for global impact categories and the annual regional emissions (typically for the region where the decision is made and used) for the rest of the impact categories.

To create a common reference system for the global (e.g., stratospheric ozone depletion) and the regional impact categories (e.g., acidification), all impacts are expressed per capita in the area for which the emissions are quantified, i.e., per world citizen for the global impact categories and per regional citizen for the rest, so that in the end all indicators will have the same unit of measure and comparisons of different impact indicators are possible. The choice of reference system should be in consistent with the goal and scope of LCA, in addition to the criteria applied in next steps of weighing and grouping, if they are to be performed (ISO 14047, 2012).

Grouping is the assignment of impact categories into one or more sets as predefined in the goal and scope definition, it either involves sorting and/or ranking. Sorting of impact categories can be done either according to spatial basis (e.g., global, continental, local scale) or area of concern of the impact category (e.g., human health, natural environment, resources). On the other hand, ranking impact categories from the most important to the least important can be performed based on reversibility of impacts, degree of certainty of impacts, or simply political priorities. In fact, ranking is dependent on value-choice, so it is subjective to individuals, organizations, and governments preference.

Weighting is the last optional step that can be carried out in LCIA. Weighting is converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices. The output of this step is providing a single numerical index (i.e., score in points) for the LCA. There is no scientific way to weigh the impacts so that one single number or overall score can be obtained, hence this step introduces the highest subjectivity in the LCA because the weighting methods and value-choices rely on individual preference. Therefore, weighting cannot be used in LCA studies intended for comparative assertion to be disclosed to the public. Weighting can be useful in routine decisions, and when the environmental aspect is just one of many other factors (e.g., economic, social, legal) influencing the decision-making process, in this case a weighting step becomes handy to express the environmental component as one number beside the other economic, social and legal information. Weighting methods are usually following one of these approaches:

- Monetization: the weighing factor is estimated by considering the expenses necessary to the fix the consequences, for instance health care system cost for diseases resulting from atmospheric pollution.
- Panel: the relative importance of damages or impact categories, the importance is assessed by panel of experts, consumers, or other stakeholders.
- Distance-to-target: it is based on the gap between the current environmental burden and a target level (e.g., planetary boundaries) (Steffen *et al.*, 2015). However, the criteria for weighting are not always presented on scientific basis, it is also heavily influenced by technical limitations and/or political and legal concerns.

2.3.1. Impact assessment methods

Impact assessment methods are ready-made packages of how the impact assessment is done that can start from the choice of impact categories until weighting. LCA software available in the market are already equipped with various impact assessment methods. Each impact assessment method includes:

- A list of impact categories
- Classification of inventory results
- A chosen indicator for each impact category
- Characterization models, and characterization factors for each impact category
- It can include normalization factors, specific grouping and weighing method.

As nowadays LCA software is the most used tool to carry out an LCA study, the assessment is done using one or more assessment methods integrated in the software. The choice of the assessment method depends on many factors. Firstly, it has to consider the goal and scope, for example, if providing a single score for the study is useful or it is better to avoid any aggregation, or if it is important for the specific study to select a method which consider land use as an impact category.

Furthermore, who is going to read the results is an important question to decide the right method to choose (e.g., researchers, decision makers or it will be available to the public). For instance, for policy makers, a single valued method can be preferred because the environmental aspect is not the sole focus of policy making, while a method which includes a weighting step should be avoided if the results will be published to the public, as the weighting factors used in the method might be controversial. Also, the geographical context can help deciding the most convenient method as some countries like Switzerland for example developed its own method, so if the study is involving Switzerland, it is better to rely on its method mainly. Nevertheless, with LCA software as a powerful computational tool, an LCA analyst can perform LCIA using many methods in few minutes, this enhances the interpretation of the results and allow more clear comparisons.

Dreyer, Niemann and Hauschild (2003) compared three of these LCIA methods emphasizing the main differences between them. Moreover, In the table below, a short description of widely used LCIA methods is provided.

Table: Brief description of some LCIA methods.

Impact Assessment Method	**Description**
IPCC 2007 GWP	Includes only climate change impact category, calculates the results for different time horizons (i.e., 20, 100, 500 years). (Forster *et al.*, 2007)
Eco-Indicator 99	Developed in Netherlands as an update of Eco-indicator 95 method. It includes normalization and weighting procedures leading to the calculation of a single value. (Goedkoop and Spriensma, 2001)
CML 2001	An update of CML 1992 method developed by Leiden University in Netherlands. It adopts a mid-point approach for calculation of indicators with no grouping or weighting.
ReCiPe	It was developed as a compromise between Eco-indicator 99 and CML 2001 as it integrates mid-point approach with end-point approach in a well-established framework. (Goedkoop *et al.*, 2009)
Cumulative Energy Demand	It focuses only on energy resources (e.g., fossil fuel resources, nuclear fuel, renewable resources of sun, wind,…etc.). (Frischknecht *et al.*, 2015)
Environmental Footprint (EF) method provided by PEF	The EF impact assessment includes a classification and characterization of the flows. Whereas normalization and weighting steps are optional, if those steps are to be applied, they should be reported under "additional environmental information". Information about classification of flows or characterization and normalization factors adopted in this method is available in EF reference packages. (Fazio *et al.*, 2018)

2.4. Phase four: interpretation

The interpretation phase consists of some logical elements to evaluate the study and draw conclusions. Firstly, the robustness of the LCA model built is assessed by applying the following checks:

- Completeness check: its objective is to ensure that all relevant information and data needed for interpretation are available and complete.
- Sensitivity check: the goal of this check is to assess the reliability of the final results and conclusions by determining how they are influenced by uncertainties in data, assumptions, allocation method or LCIA methods.
- Consistency check: to determine whether the assumptions, methods and data are consistent with goal and scope.

Moreover, in this last step of LCA, hotspots or weak points of the system studied can be determined. Hotspots means specific unit processes or groups of processes that represent the phases of the life cycle of the product with the most significant contributions to LCI and LCIA results.

To better explain and support the LCA conclusions, the estimation of uncertainties and data quality analysis is preferably done. Uncertainty is introduced into the results of an LCI due to input uncertainty and data variability. Several approaches can be followed to deal with issue of uncertainty. If uncertainty can be expressed as probability distribution or a range so statistical methods like Monte Carlo technique can be used. If not, sensitivity analysis by changing values or creating various scenarios for a model can guide the analyst to know how far the input uncertainties is affecting the results. Choices and assumptions are unavoidable during the modeling of any LCA as there is no model which will perfectly be identical to reality, so uncertainty checks help determining the range of deviation of the model virtually built from the real-life case.

Finally, conclusions, limitations and recommendations can be drawn. The objective of this part of the life cycle interpretation is to draw conclusions, identify limitations and make recommendations for the intended audience of the LCA, this should be done iteratively with the other elements of interpretations phase mentioned before. A logical sequence of this process can be:

a) Identifying hotspots.
b) Evaluate completeness, sensitivity and consistency.
c) Draw preliminary conclusions and check if they are consistent with the requirements in goal and scope (e.g., data quality requirements, predefined assumptions, methods used and study limitations).
d) If the conclusions are consistent, a report containing the results with full conclusions can be prepared, otherwise one should return to previous steps a), b) or c) as much as needed.

Recommendations shall be based on the conclusions and should be explained to the audience in accordance with goal and scope. Recommendations should be structured to help the decision maker and should be in the context of the intended application of the study in goal and scope.

3. LCA limitations

As with all complex assessment tools, the LCA methodology has its limitations as well as strengths. Some limitations are temporary in the sense that the methodology could be refined through further research and development to improve the understanding of the issue and develop clear guidance. Other limitations are inherent in the design of LCA methodology and how it was intended to be conducted. Whereas other limitations occur during application when the LCA modeler has alternative approaches from which to choose, leading to varying results from case to case. (Klöpffer, 2014)

For LCA to be conducted, some simplifications have to be adopted in order to achieve what it is intended for. The methodology is adopting a steady-state temporal approach instead of a dynamic one, as well as considering only linear relationships in LCI calculation which does not accurately represent the real system studied.

Furthermore, LCA focuses on the environmental aspect of a product life cycle, neglecting other economic and social aspects. To understand the social aspects of a product, it is recommended to apply some other tools and same applies to the economic analysis. This can be perceived as a limitation of the methodology, but it may be also seen as unrealistic expectation of what LCA is intended to do.

Another reason the methodology is criticized for, is that the environmental impact derived from an LCA study is described as “potential” impact, without specifying the temporal and spatial context. However, in most of impact assessment methods used nowadays, this element is indirectly taken care of one way or another. For example in ReCiPe end-point impact assessment, weighting factors chosen can emphasize more short term impact (i.e., human health) or long term impact (i.e., natural environment) (Goedkoop and Spriensma, 2001).

Another limitation is related to how data is conducted in databases used for building the model. As in standardized databases, the information about processes is provided in a form of building blocks without providing enough information about the comprising single processes (e.g., electricity mix production).

These limitations and more were discussed and summarized by Klöpffer (2014). The table below lists these limitations sorting them into three types: can be improved through research, inherent in the methodology, and alternate modeling choices.

Table: Examples of limitations in LCA methodology sorted in three groups. (Klöpffer, 2014)

Type of Limitation	**Examples**
Research and Development to Improve LCA	▪ Matching the goal of the assessment to the approach. ▪ Gathering the inventory data can be very resource and time intensive. ▪ Missing impact data and models for Life Cycle Impact Assessment. ▪ Dealing with life cycle inventory and impact data uncertainty.
Inherent Characteristics in LCA Methodology	▪ Distinguishing between Life Cycle Impact Assessment and Risk Assessment. ▪ LCA Does not always (usually) declare a 'winner'. ▪ LCA results should be supplemented by other tools in decision making.
Choices Available to the Modeler	▪ Allocating environmental burdens across co-products. ▪ Assigning credit for avoided burden. ▪ Expanding the boundaries (Consequential LCA).

4. Traffic light system

Based on the life cycle assessment conducted on ICRC garage waste, the recommendations are summarized in a distilled and simple way. These recommendations are provided at the end of the analysis for each type of waste and can be used by vehicles field managers, ICRC staff in delegations, as well as HQ staff to make environmentally sound decisions based on the results of scientific research, considering the recourses and options that are available to them.

The recommendations are labeled using colors to show their level of favorability. In general, three colors are used: green (ideal), amber (warning), and red (no go). The table below shows the colors and their meaning.

Table: Traffic light system recommendations and their interpretation

Recommendation	**What** is it?	**When** should it be applied?	**How** should it be applied?
Green ***(ideal)***	Green recommendations are those that: - Have a positive impact on the environment; or - Have no negative impact on the environment; or - Have a negligible negative impact on the environment.	ICRC should start any garage waste management activities from green recommendations, as they are the most environmentally friendly recommendations.	The "how?" column shows how ICRC can operationalize the recommendations (for example, through waste management kits, searching for recycling plants, etc.). It includes considerations related to quality, safety, and environment (QSE) that ICRC should take into account while following a specific recommendation. It also identifies the responsibilities of ICRC, recyclers, and other stakeholders, where possible.
Amber ***(warning)***	Amber recommendations have some negative impact.	Should be chosen only if green recommendations are not available or not economically feasible.	
Red ***(no go)***	Waste management options in the red category have significant negative impact on the environment.	Should be avoided at all costs.	

CHAPTER 4

Used Oil

1. Chapter Summary

Based on the results of ranking, presented in chapter 2, used oil was ranked as the most critical garage waste at ICRC associated with high risks of leakage and contamination of the ecological environment. It outweighs all other garage waste items in terms of waste volume, perceived criticality, and hazardousness. Unlike other waste items such as tires which remain inert in the environment for a long time, used oil stored by ICRC has a significantly higher potential to cause an environmental emergency. In 2018, a spillage of 400 liters of diesel fuel was reported at ICRC workshop in Diffa, Niger. Fortunately, the leakage did not reach underground water, however, it rang the alarm on the threats of storing used oil for a long time in ICRC workshops and motivated conducting an environmental assessment.

Currently, there is no standard procedure for ICRC delegations to deal with used oil drained from fleet and generators and each delegation deals with the used oil differently. This chapter conducts an end-of-life analysis based of life cycle assessment (LCA) methodology on the used oil in Kenya, South Sudan, and Democratic Republic of Congo. The study provides results and make recommendations in four areas. First, the results of the suggest that local solutions such as using used oil as anti-termite treatment for wood contribute to a considerable negative environmental impact and must avoided/minimized. Second, used oil recycling plants, such as Powerex refinery in Nairobi, are not devoid of issues too. Suggestions are provided to improve certain processes in such facilities. Third, long-haul transportation of used oil from ICRC garages to recycling plants, even in neighboring countries, has a negligible environmental impact and thus it is recommended to accumulate used oil in ICRC garages and then transport it to recycling plants. Fourth, anti-leakage kits are found essential for the storage of used oil in ICRC garages, but they must be accompanied with sustainable solutions after storage, such as sending to refinery or recycling facilities, to be fully effective.

2. The scope of current study

This study focuses on the environmental assessment of used oil management in ICRC workshops in three African countries: Kenya, South Sudan, and Democratic Republic of Congo (DRC). ICRC uses lube oils for various purposes such as their fleets and electric generators. The environmental assessment is conducted using Life Cycle Assessment (LCA) methodology. The study focuses the lube oil after it becomes waste, i.e., used oil, hence it can be considered an End-of-Life (EoL) assessment study.

3. Product description

Lubricating oils are one of the products which are important for humans to sustain good living standards and accomplish essential daily tasks. The main function is to decrease friction between metal surface to reduce wearing in order to extend the service life of machineries as well as saving energy. Lube oils principally consist of base oil which is either mineral (i.e., refined from crude oil) or synthetic. Around 1% of total mineral oil consumption is used to manufacture lubricants (Bartz, 1998).

Used oil is the oil that has taken up foreign substances and impurities during its operation, some of which are toxic and can represent a great hazard to the environment and public health, if not handled and disposed in a proper manner. During its service life, lube oil gets contaminated with dangerous substances such as heavy metals, polychlorinated biphenyls (PCBs), Halogens, Polyaromatic hydrocarbons (PAHs), and chlorine. Hence, used oil is considered a hazardous waste in many countries and its management is governed by a variety of national and international legislations (Speight and Exall, 2014; Pinheiro, Quina and Gando-Ferreira, 2020).

4. Geographic scope and system boundary

Kenia, South Sudan, and DRC were selected as they are suitable samples of ICRC's working environment. ICRC has a good infrastructure in Kenya and the teams from HQ and field have already worked to identify best solutions for garage waste. On the other hand, in South Sudan and DRC, there is little infrastructure in place and the amount of garage waste accumulated by ICRC and other humanitarian organizations is considerable; However, South Sudan and DRC are well connected to Kenya. Therefore, while of each these countries represent one type of ICRC's range of working environments, they collectively form a region of three adjacent countries where international and cross-border issues can also be investigated.

The boundary of study, as shown in the figure below, includes the used oil from the moment of discharge from fleet and generators to storage at ICRC workshops, and finally to recycling or disposal. A professional license of an LCA software called "GaBi" was secured for this project. Two LCA models have been built in GaBi software. The first model represents South Sudan and DRC. It starts with storage and handling phase, then transportation to construction sites. In construction sites, used oil is applied on timber to prevent termite attacks. The second model represents Kenya. It starts with storage and handling phase, then used oil is transported to a re-refinery in Nairobi called Powerex to recover base oil.

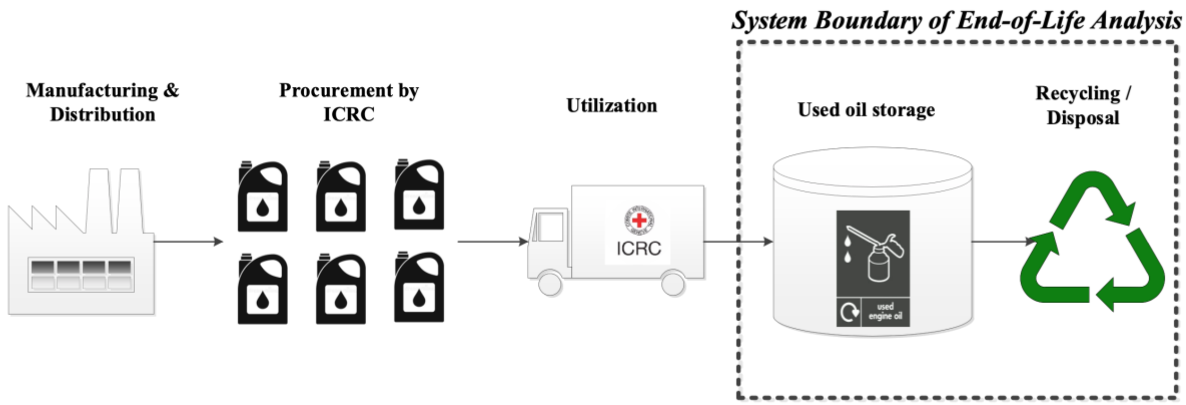

Figure: System boundary for the analysis of this study

5. Current used oil management in South Sudan and DRC

In South Sudan, all the used oil generated by ICRC around the country eventually ends up in the central garage in the capital Juba where approximately 75% of the whole country generation of used oil occurs. In the garage, all types of used lubricating oils including, for example, brake fluids are mixed and collected in an outdoor elevated steel tank with a capacity of 3000 liters. The tank is equipped with a dispenser to discharge the oil when the tank is full which happens every 2-3 months. The garage is not protected with any anti-leakage kit for the moment. Once the oil tank is full, the used oil is discharged into 200 liters drums which the virgin lube oil was shipped into when procured. These drums have good sealing properties. When the drums are ready, local buyers come to the garage with their trucks to buy the used oil.

Local contractors take the used oil and use it to treat the timber used in construction against termite attacks. The used oil is applied on the construction wood by a cloth or a sponge. Before application, the used oil is often mixed with diesel oil to reduce its viscosity and improve its permeability into wood. This is a common solution followed by the locals in South Sudan and DRC, as wood is a main construction material there and there is no access to affordable wood preservatives to protect it against termites. After treatment, the wood is used primarily as foundation for new houses by digging it up to one meter into the soil, or sometimes used for constructing house roofs. No re-refineries or solid waste treatment plant currently exist in South Sudan or DRC.

In DRC, the only clear distinction of DRC is that the used oil around the country is dealt with separately in each workshop. There is no central garage where all the oil generated around the country is stored. As the quantities stored in each workshop are not so large, there are no dedicated used oil storage tanks as in South Sudan. Thus, used oil is stored directly in the drums which the virgin lubes came in originally. The unit processes included in the analysis along with the system boundary of the system is shown in the following figure.

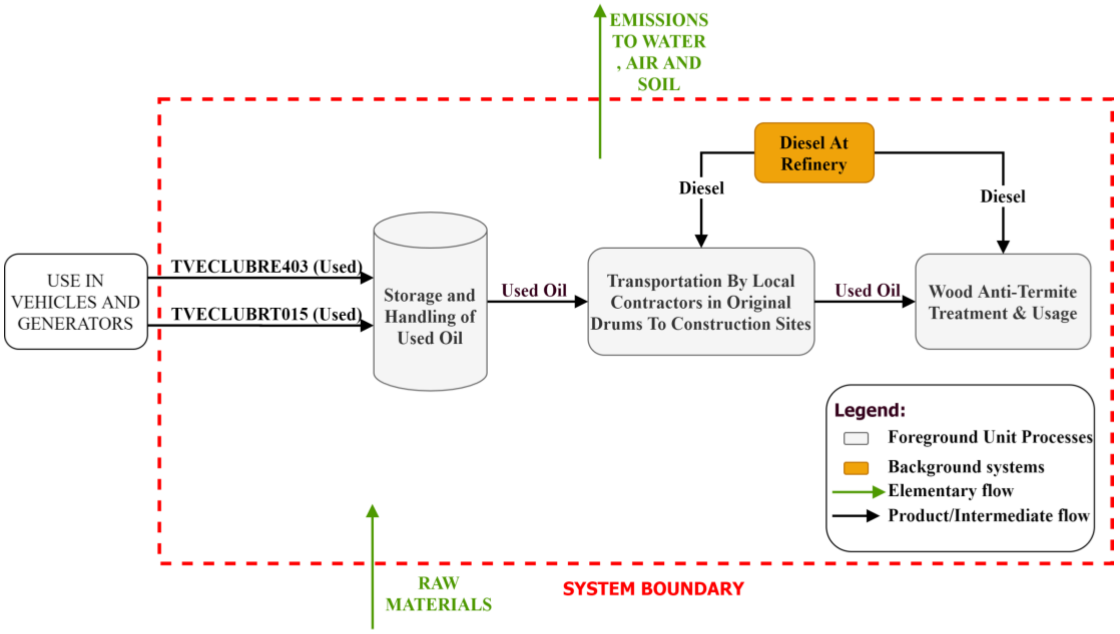

Figure: A presentation of the studied system in South Sudan and DRC

6. Current used oil management in Kenya

ICRC in Kenya has the advantage of having a re-refinery in the capital Nairobi close to their main logistics center. Powerex LTD (http://powerexlubricants.com) is a main company in lubricants and greases production business in Kenya. The main ICRC workshop in Kenya is in the capital Nairobi, where almost all the used oil generated from the fleet and generators is collected. When a sufficient amount of used oil is achieved, Powerex sends their trucks to collect it. The used oil is stored in drums. Some drums are horizontally stored with taps while others are vertically stored with or without pumps and all kinds of automotive oil is mixed the same as South Sudan and DRC. Moreover, no anti-leakage kits were installed up to the time of the data collection. Powerex uses a mix of treatment processes between distillation units and clay treatment in order to acquire the base oil. The base oil is then blended with additives to improve its physical properties to reach the recognized standards for the lube oils that can marketed. The processes at the re-refinery of Powerex have been analyzed in detail, however, they are not included in this report for the sake of simplicity.

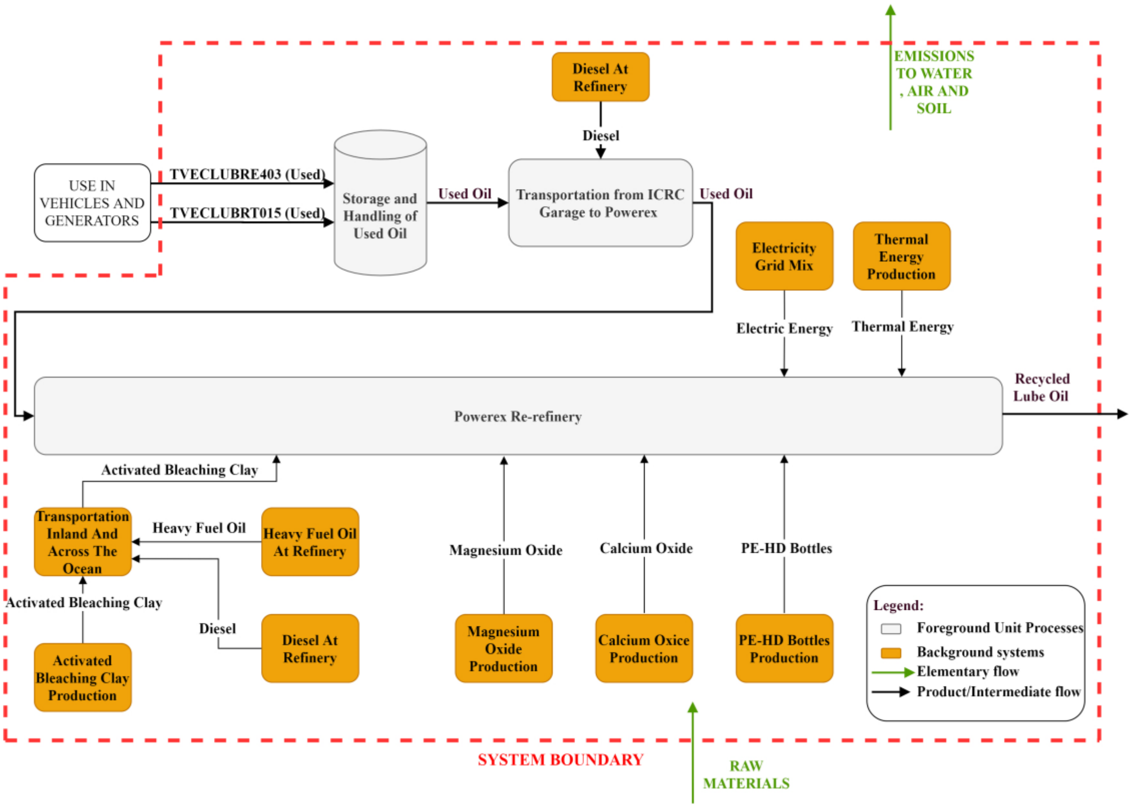

Figure: A presentation of the studied system in Kenya

7. Results

7.1. Midpoint vs endpoint impact

Results of the LCA are conducted both on *midpoint* and *endpoint* levels. It is necessary to clarify the meaning of these before presenting the results. Midpoint and endpoint levels look at different stages in the cause-effect chain to calculate the environmental impact. Let us take the example of a toxic chemical. Emission of the chemical into the groundwater leads to penetration into a nearby lake. The emission will eventually find its way to aquatic life where fish could start dying, decreasing the overall fish population, and extinction fish species in the lake. An *endpoint* level looks at environmental impact at the end of this cause-effect chain. In this example, at the extinction of fish species. A *midpoint* method looks at the impact earlier along the cause-effect chain, before the endpoint is reached. In this example, it can be the increased concentration of toxic chemical in the lake water. Endpoint results are shown as impact on *human health*, *ecosystem quality* and *resource depletion* and are easier to interpret. Midpoint results can be more difficult to interpret because they consider a large number of impacts, but they offer more detail in return.

7.2. Midpoint and endpoint results for used oil

Results of this study are referred to a functional unit of 1 liter of used oil as input to both systems. The following tables compare the two systems (South Sudan and DRC vs Kenya) in all midpoint and endpoint impact categories, respectively. Furthermore, the differences in percentage between the indicator results of both systems are provided. It was calculated by subtracting indicator results of the system with lower impact from the system with higher impact depending on the specific impact category, then the difference was referred to the higher impacting system. Green color indicates the better performing system.

Table: Comparison of systems on midpoint level

Impact Category [unit of measurement]	**South Sudan & DRC**	**Kenya**	**Difference (%)**
Climate change [kg CO2 eq.]	[redacted]	[redacted]	[redacted]
Fine Particulate Matter Formation [kg PM2.5 eq.]	[redacted]	[redacted]	[redacted]
Fossil depletion [kg oil eq.]	[redacted]	[redacted]	[redacted]
Freshwater Consumption [m3]	[redacted]	[redacted]	[redacted]
Freshwater ecotoxicity [kg 1,4 DB eq.]	[redacted]	[redacted]	[redacted]
Freshwater Eutrophication [kg P eq.]	[redacted]	[redacted]	[redacted]
Human toxicity, cancer [kg 1,4-DB eq.]	[redacted]	[redacted]	[redacted]
Human toxicity, non-cancer [kg 1,4-DB eq.]	[redacted]	[redacted]	[redacted]
Ionizing Radiation [kBq Co-60 eq. to air]	[redacted]	[redacted]	[redacted]
Land use [Annual crop eq.·y]	[redacted]	[redacted]	[redacted]
Marine ecotoxicity [kg 1,4-DB eq.]	[redacted]	[redacted]	[redacted]
Marine Eutrophication [kg N eq.]	[redacted]	[redacted]	[redacted]
Metal depletion [kg Cu eq.]	[redacted]	[redacted]	[redacted]
Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	[redacted]	[redacted]	[redacted]
Photochemical Ozone Formation, Human Health [kg NOx eq.]	[redacted]	[redacted]	[redacted]
Stratospheric Ozone Depletion [kg CFC-11 eq.]	[redacted]	[redacted]	[redacted]
Terrestrial Acidification [kg SO2 eq.]	[redacted]	[redacted]	[redacted]
Terrestrial ecotoxicity [kg 1,4-DB eq.]	[redacted]	[redacted]	[redacted]

Note: Since the results of this research will be submitted to an academic journal for publication, the numerical results are not shown in this table.

The results are available upon personal request from the principal investigator, Dr. Hossein Zarei.

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Table: Comparison of systems on endpoint level

Area of Protection	South Sudan & DRC	Kenya	Difference (%)
human health [DALYs]	[redacted]	[redacted]	[redacted]
natural environment [Species.yr]	[redacted]	[redacted]	[redacted]
resource scarcity [$]	[redacted]	[redacted]	[redacted]

Please see the note in the table above.

On midpoint level, South Sudan and DRC system performs better in 11 impact categories out of 18. On the other hand, Kenya model has performed better in seven categories. However, it is important to consider the influence of uncertainties due to assumptions in each system. Clearly, Kenya model is associated with more uncertainty because of the complexity of processes at Powerex, and with the absence of sufficient data in such complex systems, more assumptions and value choices are made which eventually reflects on the reliability of the final obtained results. For example, changing the current assumptions about bleaching clay at Powerex could influence the midpoint results. We have assumed the worst-case scenarios for Powerex as they were reluctant to provide accurate data, despite persistence of ICRC staff in Nairobi.

The comparison on the endpoint level is positively leaning towards Kenya. On the aggregated endpoint level, Kenya has lower impact in two of the environmental areas of protection: human health and resource scarcity. Hence, the used oil management system in Kenya is overall preferred from the endpoint point of view.

In South Sudan and DRC, the anti-termite process accounted for more than 93% in all midpoint impact categories. Moreover, in Kenya, Powerex re-refinery is the principal contributor with approximately 100% in all midpoint categories. The highest added impact inside the refinery was associated to activated bleaching clay production with above 70% contribution in 13 impact categories. This specific type of clay is imported to Kenya from India and used in the recycling process of used oil in the re-refinery.

7.3. Sensitivity analysis

Two sensitivity analyses were carried out. The first one was to assess the influence of variation on leakage amount during storing, and the variation of transportation distance on the overall indicator results of the South Sudan and DRC system. It was found that changing the leakage percentage by ±50% of the original value does not have a considerable impact on the indicator results. Thus, the system is not sensitive to the assumed leakage percentage at least in the margin of ±50% from the originally assumed value. The transportation distance in South Sudan and DRC was not very effective on the indicator results as well. A standard deviation equal to 55.6% was used in the analysis, however the effect did not exceed 5% on any indicator.

The second sensitivity analysis was done on one of the assumed parameters in Kenya model which is the amount of washing water used in washing and filtration phase of activated clay production. This water will end up as acidic sludge and continue to the sludge treatment unit. By decreasing the amount of water to one third of the originally assumed value, all indicators changed dramatically except for four impact categories.

It was not possible to collect primary data from Powerex about the details of the re-refinery process and therefore, we have used an old model for manufacturing activated bleaching clay as the worst-case scenario. This assumption might not hold in practice. It is highly recommended that future modeling of the re-refinery is done using primary data of activated bleaching clay manufacturing process. Based on the results of the current model, this process was found to be the most impacting one and the results were found to be highly sensitive to this specific process. Using primary data can provide a more realistic and certain picture of how this process is contributing to the overall system impacts.

8. Recommendations

To interpret the results, it is noteworthy to highlight that based on LCA, it is difficult to say that one system is "better" than the other in a general sense. The context is a key factor. Some organizations give specific impact categories, such as global warming potential, a priority because practically, it is very unrealistic for a system to environmentally outperform in all impact categories. This was clear in the comparison between the two systems.

R1: Overall, processing used oil in a re-refinery (such as Powerex) is strongly recommended over uncontrolled local practices such as using used oil as anti-termite treatment. Applying used oil as anti-termite treatment and mixing it with diesel should be primarily avoided, if at all possible. Otherwise, local contractors can be advised to reduce or refrain from mixing used oil with diesel as it considerably adds to the negative environmental impact.

R2: Within Powerex refinery, or similar plants in other countries, some processes could be improved to reduce the negative environmental impact. For example, in all impact categories, activated bleaching clay production is the highest contributor to the impact from the refinery. The whole system was found sensitive to the of activated bleaching clay manufacturing process. Therefore, it is recommended that this process is optimized by Powerex to reduce the negative impact. Moreover, due to the significance of this process, collection of primary data from the Powerex or other re-refineries is highly recommended. This was not possible in the current study.

R3: The impact of transportation was found to be negligible on environmental impact in both systems. This means it is recommended to transport waste to re-refinery or recycling center, even if it is located in another country or within a long distance. We have tested transporting used oil by a rather polluting truck from Kampala to Yuba (about 640 km) and no significant changes in the results were found.

R4: Leakage prevention kits are essential and must be used in all contexts. In addition, the study found that using these kits per se is not sufficient and must be accompanied with sustainable disposal options such as refinery. Preventing leakage during storage at ICRC garages is essential but will become futile if used oil is used for local solutions such as anti-termite treatment.

9. QSE considerations

This section reviews some of the necessary questions to be asked related quality, safety, and environmental (QSE) aspects. Currently, ICRC uses a set of questions and a rating method to assess the QSE appropriateness of its suppliers (QSE Company Assessment Form). This section will not repeat the questions that were already addressed in the form. Nor it provides a comprehensive list of QSE-related questions for all the products.

This section aims to provide the critical questions that need to be asked before selecting a solution from the proposed colored recommendation system. These questions are based on the results of the environmental study conducted in this project and therefore they mainly involve questions around the waste management and disposal, rather than fresh production. The possible or ideal answers are provided. These questions can be added to the current QSE Company Assessment Form, to help ICRC staff evaluate the sustainability of waste management options and assist them in the decision-making process.

Before moving to company assessment, it is recommended that for all waste types, the QSE assessment asks the ICRC staff "*how do you manage the waste?*". Currently, limited information is available about how ICRC deals with different types of waste across different delegations. The answers can sketch a better picture of what happens to garage waste immediately after they are generated. The relevant questions and answers for used oil are as follows:

- Which materials are recovered and which materials are wasted at the end of the re-refinery?

Possible answers: Re-refining final product is "recycled lube oil" for market provided that upgrading base oil happens on site at the final stage of mixing with additives to improve its characteristics. If this stage does not exist, the only recovered product is "base oil" which is the recovered oil from the re-refining process after distillation and bleaching. Base oil usually requires further enhancement before being sold in the market and use in automobiles.

Possible byproducts: diesel, gasoline, bitumen

Possible wastes: oil saturated clay (only if the re-refinery uses an activated bleaching clay treatment)

- What measures do you take to control the emissions?

Ideal answer: Processes like distillation which occur at high temperatures and high pressure should be done under controlled conditions and monitored for potential emissions to air (e.g., heavy metals and volatile organic solids) that can be released under these extreme conditions. Furthermore, if thermal energy is to be produced on site to feed the distillation unit, flue gas treatment for the incinerator should exist. Components of the flue gas treatment system can vary according to the type of fuel used.

- What source of energy do you use for your recycling process?

Possible answers: Renewable energies (highly preferred), natural gas (preferred), light fuel oil (less preferred), and coal (least preferred). As for electricity, if taken from the grid, choosing the electricity that is certified to be renewable, where possible. As for the thermal energy, which is usually produced by the facility internally, cleaner sources like natural gas are preferred.

- How do you transport used oil?

Ideal answer: Train, where railway is accessible. Sealed tanker trucks, for road transport.

- What do you do in case of oil spillage? (This question applies to ICRC staff too, if they store any used oil)

Ideal answer: Handle the spilled oil as a hazardous waste. Oil leaks and spills must be dealt with it immediately as it could cause a serious pollution. If you can safely stop the flow of oil do. Put a bucket under the leak and close valves or taps. Use leak sealing putty from your leakage prevention kit to cover the leaking area, wear rubber or vinyl gloves to protect your skin. For plastic tanks you may be able to temporarily stop the leak by rubbing a bar of soft soap across the leak.

Use the contents of leakage prevention kit or sandbags to absorb the spilled oil if it’s on a hard surface and stop it entering a river, stream, drains or soaking into the ground. Never wash any spilled oil away into drains or into the ground as most drains connect to watercourse. Never use detergents to clean up spilled oil as it could cause a worse pollution incident. The detergent itself is a pollutant and mixes oil into the water.

If the oil has soaked into the soil or ground, you’ll need to act quickly to prevent it soaking further into the ground and reaching building foundations or groundwater supplies. You’ll need a professional company with training and accreditation to clean up oil that’s soaked into the ground. Removal and disposal of soil contaminated with oil can be very expensive.

10. Traffic light system recommendations

The following table shows the traffic light system recommendations for the used oil. For a guide on what each color in the traffic light system means and how the system should be used, please refer to the end of chapter 3 (methodology).

Used oil	**What?**	**When?**	**How?**
Green *(ideal)*	Recycling (i.e., re-refinery)	To manage used oil collected from vehicles and generators	Recycle used oil in recycling plants (i.e., re-refineries). In traditional recycling plants, the usage of activated clay in bleaching the used oil creates the highest negative environmental impact. The plant is recommended to optimize the use of activated bleaching clay. If different plants are available, choose the one which applies another technology than activated clay. Moreover, always choose the plant with *the highest percentage of base oil recovery, highest energy efficiency, cleanest source of energy (natural gas or electricity from renewables)*, and finally *the most robust emissions control system.*
	Energy recovery by incineration	To manage used oil collected from vehicles and generators	It is a viable option *only when* the facility is certified to deal with hazardous waste incineration and equipped with flue gas abatement and emissions control. The facility can be: - A stand-alone waste to energy plant (WTE) generating heat or electricity, or both, - A complex facility in another industrial context such as a cement manufacturing plant, using used oil for incineration in their kilns.
	Distillation	To manage used oil collected from vehicles and generators	Distil used oil to produce combustible products such as marine diesel oil fuel and by-products such as asphalt and light ends (this might be a less common approach in developing countries).
	Transport	To send used oil to recycling plants	Where the recycling plant is located in remote areas, it is recommended to transport used oil. Even if the recycling plant is located in a neighbor country more than 700 km away, it is still environmentally beneficial to send used oil, despite the emissions of transportation. Choose suitable means vehicles: sealed tanker trucks are the best option to avoid leakage. Where possible, work with approved waste transportation companies with transport licenses for the movement of hazardous waste.
Amber *(warning)*	Storage	To store used oil until sent to recycling plant	Use leakage prevention kits for the containers.
Red *(no go)*	(Do not) give to local population or local contractors who use it as anti-termite	Never	Record the amount of waste, location, and the time for which a red solution has been used and report this information to the HQ. In the inevitable case of using as anti-termite by local population and contractors, they should be advised to reduce or refrain from mixing used oil with diesel as it considerably adds to the negative environmental impact.
	(Do not) landfilling or open dump	Never	

CHAPTER 5

Used Oil Filters

1. Introduction

From the ranking shown in chapter 2, it was concluded that one of the most critical garage wastes is automotive used oil filters used in vehicles by ICRC delegations. This chapter compares the most common disposal options for oil filters that are currently taking place in the different delegations. To decide these most common disposal options, a survey was sent to various delegations around the world, asking them about the way they deal with such waste in their countries. The responses were received from more than 70 delegations. The summarized results of this survey for what concerns oil filters are reported in table below. Furthermore, according to these answers, the conclusions are reported in the same table transforming the theoretical answers of the delegations into proper environmental terms, hence waste management scenarios to be analyzed.

Table: Conclusions of the delegations' survey about used oil filter management

	Oil filters
Answers from survey on management scenarios	1) The waste is properly managed. Sold or donated to a certified waste management. (around 30% of answers) 2) Donated/sold to a waste management company but I am not sure how it's managed (around 20% of answers) BUT at the same ranking (also 20%) there is: 3) Disposed together with the normal delegation waste.
Conclusions	From no. 3 above it can be said that if it is disposed with normal waste, it will be landfilled assuming that some of these countries do not have separation nor proper incineration plants. From no.1 & 2 we can consider a recycling process: in fact, it is very common for oil filters to be recycled given the simplicity of the process, the available technologies, and the potential profits of recyclers from secondary materials production.

2. LCA of used oil filters

2.1. Goal definition

The goal of this study is to help ICRC decide the most environmentally sound solution for the management of used automotive oil filters they generate throughout the lifetime of the different vehicles operating in the different delegations around the world. Two general end-of-life scenarios will be compared which are:

- Typical recycling process of used oil filters,
- Total landfilling without any preprocessing.

The expected audience of the study is the ICRC staff. On one hand, the headquarters can use it as a reference for strategic planning besides the other related studies carried out by the ICRC to improve their environmental performance in general. On the other hand, another party who could benefit from this study is the field operators in the different delegations.

2.2. Scope definition

As the function of the system is the management/disposal of automotive used oil filters, the functional unit was chosen to be the management/disposal of 1 ton of filters. This was the most suitable functional unit of the product under study given that this waste stream is usually expressed in tons in references and rarely treated as a single unit, therefore this choice will facilitate building the inventory from the available data.

The study has no geographical context as the purpose is to use its result as general guidelines for ICRC delegations all over the world. Therefore, average global values were always used whenever possible.

No primary data is available for this preliminary study. Only available literature or/and datasets of Ecoinvent database will be used as data sources. When neither is available, assumptions will be made based on the modeler experience. It must be noted that assumptions may affect the quality of results by introducing uncertainty, however given that the study is preliminary and given the goal of the study, this level of quality is acceptable. The sources of data will be mentioned in the inventory section.

The life cycle impact assessment method considered will be ReCiPe 2016 v1.05 given its global validity. The grouping of endpoint impact categories as recommended by ReCiPe 2016 will be shown. Recipe 2016 groups the endpoint impact categories into three areas of environmental concern:

- Damage to human health,
- Damage to ecosystems,
- Damage to resources availability.

For more information about life cycle impact assessment methods, check the annex.

2.3. Recycling scenarios

The system boundary starts with transportation of waste to recycling plant. However, as this study targets a general geographical context, different distances will be tested to understand relatively how far transportation phase contributes to the environmental impact of such system and how the distance can influence the results.

The next station for the oil filters is the recycling plant. No literature nor datasets were found that discuss the recycling of used oil filters. So, a typical recycling plant as described by leading manufactures of used oil recycling plants were used to know the main components of such plants. The system boundary is described in figure below.

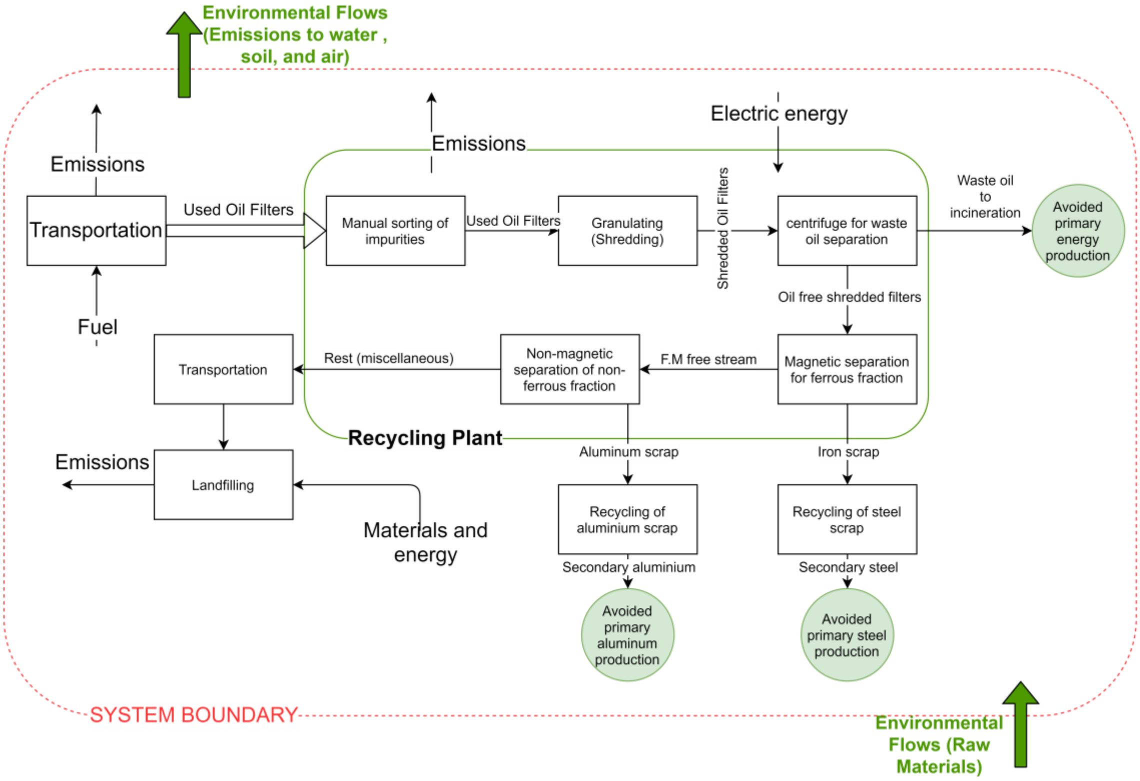

Figure: System boundary of used oil filters recycling scenario

According to ANDRITZ, an international technology group that provides recycling solutions for many waste streams, a typical recycling plant for used oil filters follows the following sequence:

1. Storage of the received oil filters in a place with proper drainage system to catch any excess liquid waste oil from the filters (not shown explicitly in the figure above);
2. The filters are moved to a conveyor belt to go through a manual sorting phase to take out the extraneous materials;
3. Granulating or shredding of filters to reach a suitable size for the next steps;
4. Centrifuge to separate the waste oil (i.e. liquid);
5. Separation of ferrous fraction by using magnetic separators;
6. Separation of non-ferrous fractions by using non-magnetic separators;
7. The remainder is discarded as a non-recoverable fraction.

Almost the same plant scheme was reported by SA ENG, an Italian company operating in the same field. The inputs to the system from background unit processes are fuel for transportation and electricity to run the recycling plant. For the outputs no direct emissions due to the recycling process could be considered assuming that the plant is in good conditions with no leakage of liquids to external environment. Hence, emissions will only be generated from the background processes like electricity supply, transportation, waste oil treatment and landfilling.

The main function of this system is to manage the waste stream of used oil filters, however as any recycling system, secondary materials are produced. Consequently, the system here is multifunctional which means that it does treat the waste but at the same time it produces valuable by-products as outputs which is a secondary function of the system.

This kind of multifunctionality problem is addressed here by applying the substitution by system expansion method (i.e., avoided impact concept). The concept is quite straightforward. As the system produces secondary materials that can replace primary materials that are to be produced from raw resources, our system here shall receive environmental credit for that. This can be expressed mathematically as environmental impacts with a negative sign.

The main recovered materials here are iron and aluminum scraps from which secondary steel and secondary aluminum can be produced. Hence,_a recycling phase of iron and aluminum scrap was also included in the system as shown in the above figure. These processes represent the transformation of metal scrap into secondary material that are ready to substitute materials produced from primary resources. Details about the modeling of these processes can be found in table below.

Moreover, heat and electric energy can be recovered from the waste lubricating oil incineration. The substituted production technologies for each flow are mentioned in the next table after the iron and aluminum recycling processes. The inventories of the different technologies are acquired from Ecoinvent 3 database.

Table: Recycling processes of iron and aluminum scrap.

Input Material	Recycling processes dataset	Notes
Iron scrap	Steel, low-alloyed {RoW}| steel production, electric, low-alloyed | Cut-off, U	This dataset describes the steel production for reinforcing steel in Austria from secondary steel (iron scrap) in an electric arc furnace. The iron scrap is melted in the electric arc furnace and alloys are added. After the melting process, the steel is case into billets. The billets can then be hot rolled and used as reinforcing steel in construction. According to the dataset the recycling efficiency is 90%
Aluminum scrap	Aluminum scrap, post-consumer, prepared for melting {RoW}| treatment of aluminum scrap, post-consumer, by collecting, sorting, cleaning, pressing | Cut-off, U	Scrap preparation begins with receiving of aluminum scrap. The actual activities can include shredding, sink and float, cutting and baling, drying and de-oiling, de-lacquering, dismantling. According to the dataset the recycling efficiency is 80%.

Table: Substituted technology by each by-product of the system.

Secondary material/ generated waste	**Substituted technology/ waste treatment**	**Notes**
***Secondary steel* after iron scrap recycling**	Steel, low-alloyed {GLO}| market for | Cut-off, U	The impacts associated with the production of primary steel will be credited taking into account a substitution ratio of 70% (Rigamonti, Grosso and Niero, 2017)
***Secondary aluminum* after aluminum scrap recycling**	Aluminum, primary, liquid {GLO}| market for | Cut-off, U	The impacts associated with the production of primary aluminum will be credited to the system taking into account substitution ratio of 42% (Koffler and Florin, 2013)
Waste oil	Waste mineral oil {RoW}| treatment of waste mineral oil, hazardous waste incineration, with energy recovery | Cut-off, U	Waste oil is assumed to be incinerated (in a proper facility for hazardous waste incineration): energy from combustion is recovered to produce heat and electricity as modeled in the Ecoinvent dataset. Net energy produced in hazardous waste incineration: 25.82 MJ/kg thermal energy and 2.44 MJ/kg electric energy. One kg of this waste produces 0.01143 kg of residues which are landfilled. A solidification process is carried out with 0.004571 kg of cement.

The remaining part after non-ferrous fraction removal is assumed to be landfilled. This is the worst-case scenario because if the remaining part is incinerated for example, the system will receive more credit for energy recovery than any credit from landfilling if there is any. The transportation between recycling plant and landfill is considered with an assumed distance (this one is also tested in the sensitivity analysis) as it is not realistic to omit it because usually landfills are far from recycling facility that can exist close to residential areas unlike the landfills.

No transportation however was modeled between the oil filter recycling plant and the waste oil incineration assuming that they exist together within the same perimeter. On the other hand, the transportation of iron and aluminum scrap to their recycling plant was decided to be included or not depending on the substituted dataset. If the substituted dataset from Ecoinvent included transportation in its activities, then a transportation step was taken into consideration for the metal scrap. The idea was to have fair comparison on pure “gate to gate” basis. Gate to gate system boundary refers to the production phase. For more information about similar terms, see the annex.

2.4. Landfilling scenario

The proposed landfilling system assumes that the used oil filters will be landfilled as they are without any pretreatments. The landfilling process is modeled using a combination of landfilling datasets depending on composition of used oil filters. This will be better explained in the next section of system inventory. The system boundary can be expressed as in figure below. It includes transportation of used oil filters to the landfill then the landfilling process.

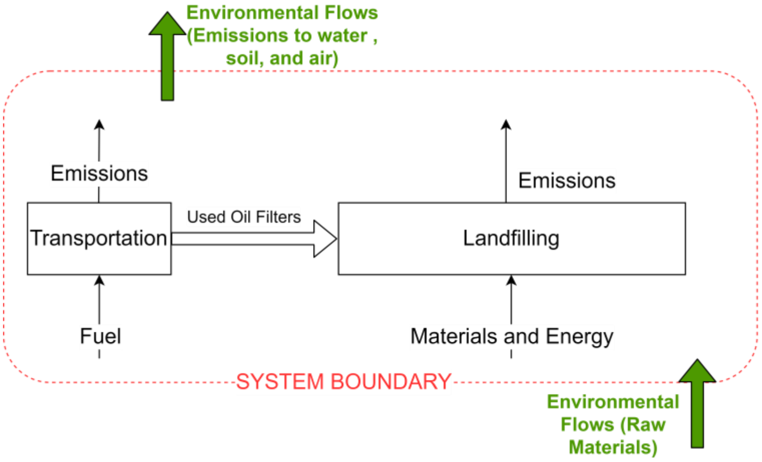

Figure: System boundary of used oil filters landfilling scenario

2.5. Inventory

According to ANDRITZ, used oil filters consist of some 60% metals (mainly iron). The oil accounts for around 20% of the material mixture. The actual paper filter, rubber sleeves, and other plastic parts make up the remainder. By taking into consideration these percentages and by making some rough assumptions, the composition referred to one ton of used oil filters considered in the study is shown in table below.

Table: Used oil filter mass composition

Fraction	% (weight)	Mass (t)	Notes
Metals (Iron)	50	0.5	Total 60% metal from ANDRITZ, assumed 50% iron.
Aluminum	10	0.1	Total 60% metal from ANDRITZ, assumed 10% aluminum.
Retained oil	20	0.2	Taken from ANDRITZ
Miscellaneous (paper, rubber, and plastic)	20	0.2	Taken from ANDRITZ

The transportation of the oil filters in both scenarios (i.e., recycling and landfilling) is modeled using "Transport, freight, lorry, unspecified {RoW}| market for transport, freight, lorry, unspecified | Cut-off, U" dataset acquired from Ecoinvent 3 database.

In the recycling scenario, an average electric demand for each unit in the recycling plant is shown in the table below along with the source of data. The conveyor belts electric consumption is omitted as it is usually negligible compared to the machines, also because the system here is an imaginary system so the length of the belts couldn't be quantified.

Table: electric energy consumption of recycling plant units.

Unit process	Electric consumption	Source	Additional notes
Manual sorting	-	-	Assuming no electricity is used at this phase
Granulator (shredder)	20.83 kWh/t input	Universal Granulator UG technical specifications by ANDRITZ	Throughput up to 6 t/h. Taken 6 t/h
Centrifuge	3 kWh/t output (dry filters)	https://www.process-worldwide.com/filtration-equipment-selection-criteria-a-300953/?p=3	Average pusher centrifuge (common solid/liquid separation centrifuge used in many applications)
Magnetic separator	0.3 kWh/t input	(Grosso, 2019)	Permanent magnet type
Non-magnetic separator	1 kWh/t input	(Grosso, 2019)	Eddy current separator for non-ferrous metals removal

To estimate the total energy consumption of the recycling plant, a mass balance is needed to quantify the input and output of each machine in the recycling plant (following figure). An important assumption here is that mass of impurities that is sorted out in the first phase of the recycling plant is negligible, so the mass balance is calculated assuming pure stream of used oil filters with the composition in the following table. This approximation was made due to the absence of data about the mass percentage and the nature of impurities in the waste stream.

Furthermore, for simplification, metal recovery units (i.e., magnetic and non-magnetic separators) are assumed to have 100% efficiency so there is no metal loss in the final output flow ending up in the landfill. Same applies to centrifuge for liquid separation which means that 100% of oil is removed in this unit.

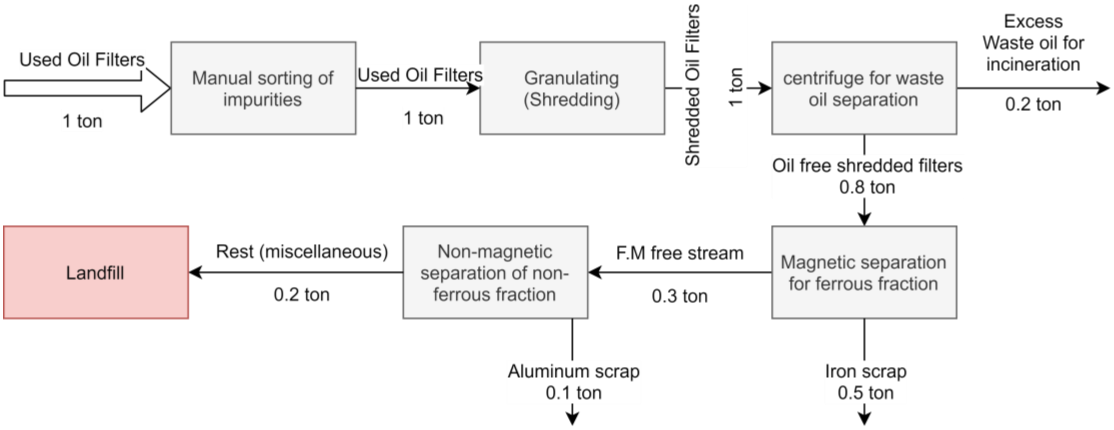

Figure: Simplified mass balance of the recycling

According to this mass balance electric energy consumption of this hypothetical recycling plant is roughly 24 kWh/t of used oil filters input to the system. The electricity is assumed to be provided in medium voltage and is modeled using the ecoinvent dataset “Electricity, medium voltage {GLO}| market group for | Cut-off, U”

The amount of iron and aluminum scrap produced is 0.5 and 0.1 t respectively, while the excess waste oil amount from the process is 0.2 t. The remaining miscellaneous flow of paper, rubber, and plastic is 0.2 t. To model its landfilling, it was assumed to be 25% rubber, 25% plastic and 50% paper given that paper is the active component in an oil filter. This was necessary given the different behavior of each material when landfilled and the available datasets in Ecoinvent. Rubber was modeled using “Inert waste, for final disposal {RoW}| treatment of inert waste, inert material landfill | Cut-off, U” as rubber is considered inert material. Plastic was modeled using “Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, sanitary landfill | Cut-off, U” dataset. Finally, paper was modeled using “Waste graphical paper {RoW}| treatment of, sanitary landfill | Cut-off, U” dataset.

For the landfilling scenario on the other hand, a combination of landfilling processes obtained from Ecoinvent database was built based on the composition of used oil filters as illustrated in table below.

Table: Datasets used in landfilling scenario

Material	Mass percentage	Associated dataset	Notes
Iron scrap	50%	Scrap steel {RoW}| treatment of, inert material landfill | Cut-off, U	-
Aluminum	10%	Waste aluminum {RoW}| treatment of, sanitary landfill | Cut-off, U	-
Waste oil	20%	Refinery sludge {RoW}| treatment of, sanitary landfill | Cut-off, U	The dataset was chosen as the closest representative dataset of waste oil landfilling.
Paper	10%	Waste graphical paper {RoW}| treatment of, sanitary landfill | Cut-off, U	As assumed in the final stage of the recycling scenario.
Rubber	5%	“Inert waste, for final disposal {RoW}| treatment of inert waste, inert material landfill | Cut-off, U”	As assumed in the final stage of the recycling scenario.
Plastic	5%	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, sanitary landfill | Cut-off, U	As assumed in the final stage of the recycling scenario.

2.6. Impact assessment and interpretation

To show the results of the recycling scenario, an initial transportation distance of 100 km was assumed. This distance is divided between 50 km from used oil filters collection center (i.e., garage or workshop) to the recycling plant, and 50 km from the recycling plant to the inert landfill. The total results representing the three areas of environmental concern are showed in The following table in addition to the contribution of each process.

Table: Recycling scenario impact assessment assuming 100 km total transportation distance

Damage category	Unit	Total
Human health	DALY	0.002298
Ecosystems	species.yr	-0.0000035
Resources	USD2013	-31.572415

According to ReCiPe 2016 method, damage to human health is measured in disability adjusted life year (i.e., years). One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population. Ecosystem is measured in species.yr which can be interpreted as average species disappearing per year due to the damage to ecosystems. Lastly, damage to resources is represented in US dollars currency. Huijbregts *et al.* (2016) provides deeper explanation of ReCiPe method and units used to express impacts.

From the table, the Total column shows negative results in two damage categories which are ecosystems and resources. This is due to the adoption of substitution by system expansion method to deal with multifunctionality. This means that the avoided impacts of primary production of steel and aluminum, plus the avoided production of primary energy thanks to waste oil incineration are far more than the added impacts of the system under study. This is an excellent indicator that such system shows good environmental performance in these two damage categories thanks to the material and energy recovery. Nevertheless, human health does not follow the same pattern.

The following figures show the contribution of each activity in the overall system under study. While in ecosystems and resources metals recycling had a good impact on the overall performance of the system, it played an adverse role in human health. By analyzing this phenomenon further, it was found that the recycling process of iron scrap is the reason behind it. In electric arc furnace, which is used in steel production from iron scrap, furnace slag (by-product) is generated and needs to be disposed. The disposal by landfilling of this slag is the main responsible for this final result in human health category.

Therefore, it is recommended to find more environmentally sound way to deal with slag from the arc furnace in iron scrap recycling facility or choosing another technology of iron scrap recycling that does not produce a big amount of slag. If this drawback could be eliminated, the overall results concerning human health can change drastically.

Another takeaway from the figures below is the negligible contributions of transportation, and electricity consumption in the oil filter recycling plant. This is valid for the three damage categories. Landfilling of the residues of oil filter recycling plant had instead a considerable contribution in the ecosystem category.

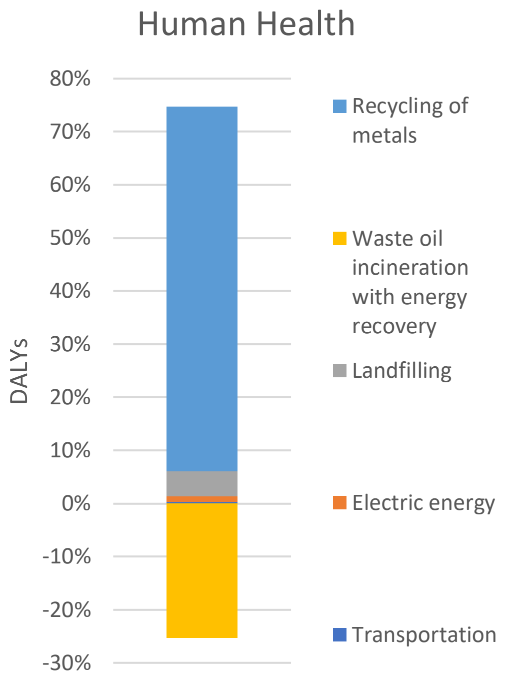

Figure: Human health category process contribution

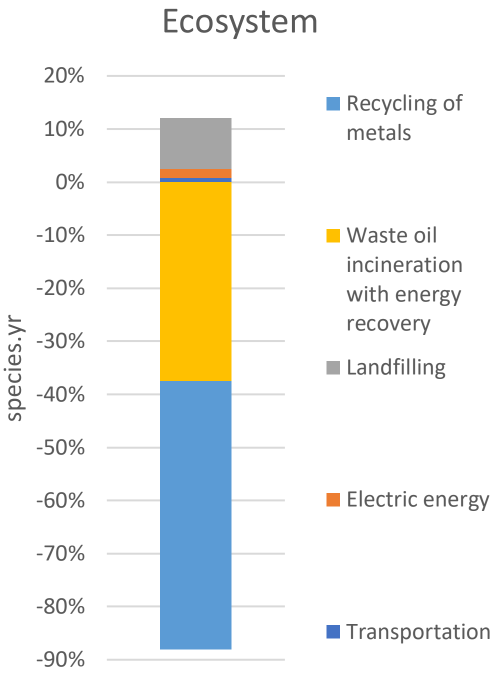

Figure: Ecosystem category process contribution

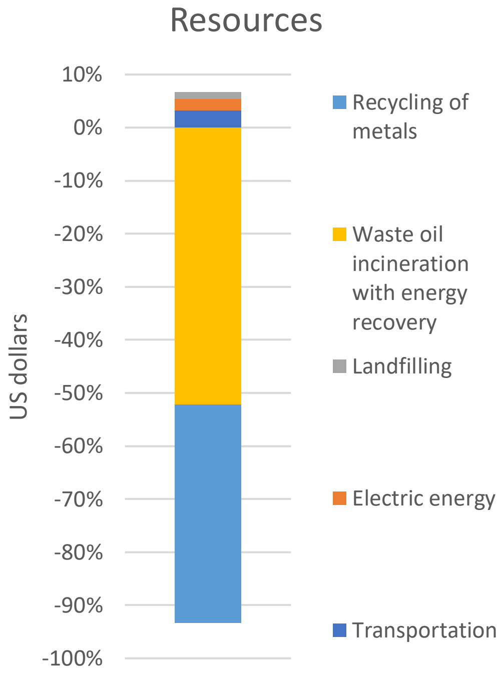

Figure: Resources category process contribution

Furthermore, the sensitivity of the system to the distance variation was tested by trying different distances to check how far transportation distance can affect the overall results. Five additional distances were tested: 20 km, 200 km, 400 km, 800 km, and 1000 km. It must be noted that these distances represent the total truck transportation distance in the system, and it is always divided 50:50 between transportation to recycling plant from oil filter collection center and transportation from recycling plant to the landfill.

As the transportation in figures above was not broken down into the two transportation stages in the system, it is worth highlighting that the first transportation stage to the recycling plant has always higher impact because of the higher payload of the truck (1 ton of oil filters compared to 0.2 ton of recycling residues going to the landfill) and given that the transportation type and distance are equal in the two transportation stages.

The effect of the distance on the total impact of the system is shown in the following table while the variation of transportation contribution to the overall impact can be seen in following figure.

Table: Effect of transportation distance on the total impacts of the system in the recycling scenario.

Damage category	Unit	20 km	100 km (Baseline)	200 km	400 km	800 km	1000 km
Human health	DALY	0.0023	0.0023	0.0023	0.0024	0.0024	0.0025
Ecosystems	species.yr	-0.000004	-0.000004	-0.000003	-0.000003	-0.000003	-0.000003
Resources	USD2013	-32.513	-31.572	-30.397	-28.045	-23.343	-20.991

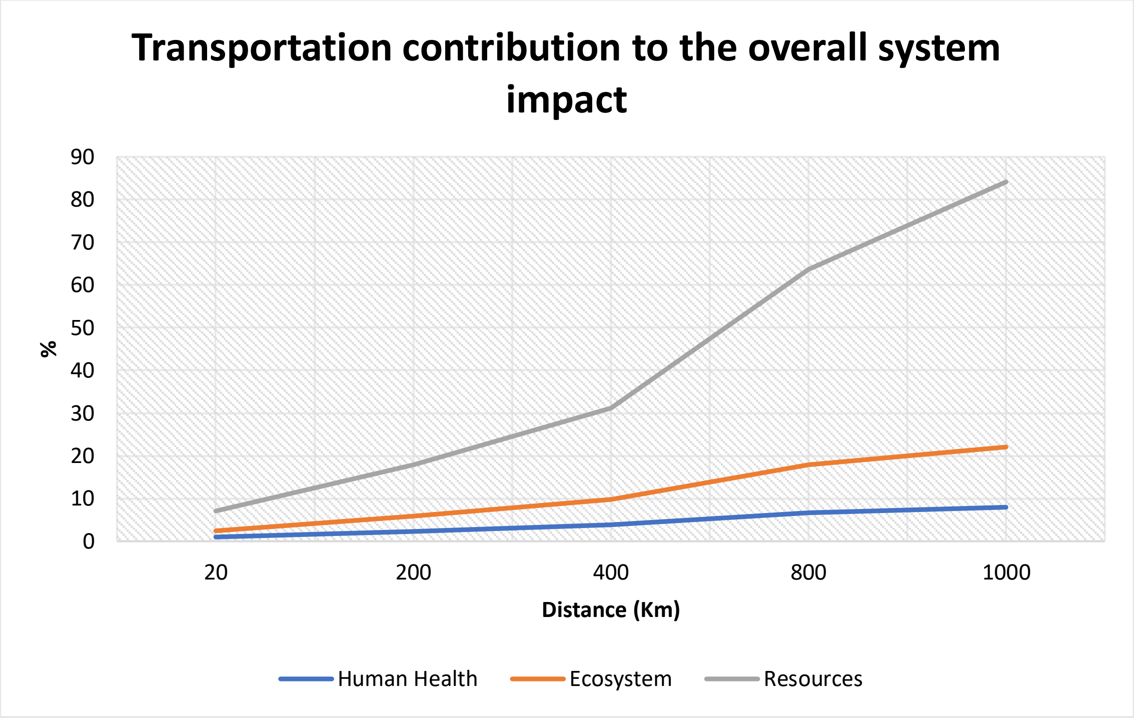

Figure: Transportation contribution variation with distance.

It is obvious in the table above that the main trend does not change. Generally, the avoided impacts are still significantly dominating the results and we have overall negative results in ecosystem and resources damage resources. So, it can be said that transportation does not affect much however by increasing the distance, some of the system environmental credit is lost. This can be noted obviously in resources category which is also demonstrated through the slope of resources line in the figure above. Being steeper than the other lines is an indication that this category is the most sensitive to any increase in distance.

In conclusion, there is no turning point for transportation in which transportation changes the impact of the system dramatically even with distances beyond 1000 km. Nevertheless, only the resources damage category was found to be sensitive to distance variation. In the following table, the indicator of resources worsens by around 10% if the distance increases from the initially assumed total distance in the baseline scenario (i.e., 100 km) to 400 km but still in the negative domain.

The landfilling scenario of oil filters is more straightforward. The results representing the final indicator results and contributions of each main unit process in the system are illustrated in the following figures.

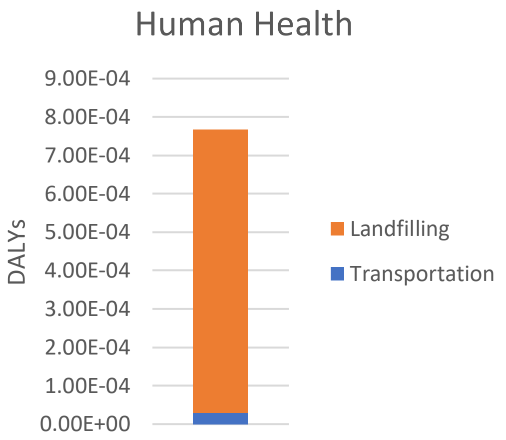

Figure: Landfilling scenario human health indicator

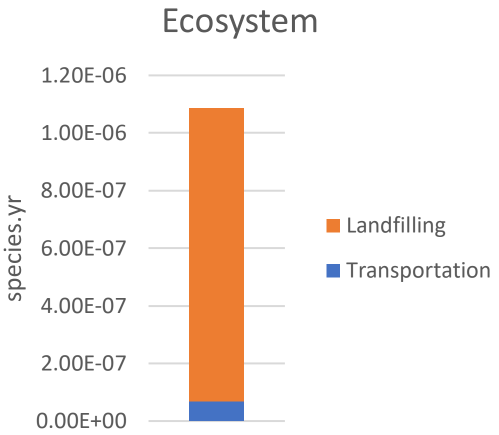

Figure: Landfilling scenario ecosystem indicator

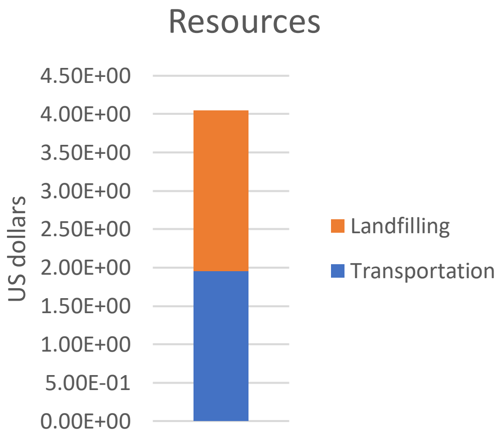

Figure: Landfilling scenario resources indicator

As the main system is not multifunctional like the recycling so a system expansion to include the avoided impacts was not necessary. Thus, there are no negative sign contributions. In damage to human health and to ecosystems, the landfilling processes itself dominated the result which means transportation does not play a significant role here. However, for damage to resources, the percentage of transportation was around 50% of the final impact indicator result (results were obtained with 100 km transportation distance assumption).

Lastly, the table below compares the two waste management options of used oil filters. With recycling at 100 and 1000 km having a negative sign in ecosystems and resources damage categories, it can be clearly said that recycling is better here. Nonetheless, interestingly landfilling is performing better in human health category. The reason for that was mentioned before. The high impact on human health for recycling is due to the iron scrap recycling process or more specifically due to the treatment of slag from the electric arc furnace used in melting the iron scrap.

Table: Comparison between landfilling and recycling of oil filters.

Damage category	Unit	Landfilling (100 km)	Recycling (100 km)	Recycling (1000 km)
Human health	DALY	0		
Ecosystems	species.yr	1		
Resources	USD2013	4		

Note: Since the results of this research will be submitted to an academic journal for publication, the numerical results are not shown in this table.

The results are available upon personal request from the principal investigator, Dr. Hossein Zarei.

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3. Conclusions and recommendations

The following conclusions and recommendations can be derived from the LCA results:

- Recycling of used oil filters is preferred over landfilling in any case even if the system involves long transportation distances. This conclusion was expected, and it complies with the general waste hierarchy developed by the European Directive.
- If it is possible to assess the recycling plant (of oil filters), it is recommended to make sure that the machines mentioned in the system developed in this study exist there in reality (especially magnetic separator and Eddy Current Separator) to maximize the recovery of materials and reduce the useless stream that go to landfilling. A choice between available recycling plants can be done based on these criteria. The plant studied here is a typical plant of oil filters recycling that should not differ much from one place to another.
- If possible, the waste of the oil filters recycling plant (i.e., the residues) is recommended to be sent to energy recovery legal incinerator rather than landfilling.
- Making sure that the extracted used oil is dealt with in a proper incinerator that can treat such hazardous waste with adequate flue gas treatment system for example. If proper incineration is not present, re-refining can be an alternative. Both are the most common legal ways to deal with used lubricating oil (Eltohamy, 2021).

- To address the human health drawback of iron scrap recycling in electric arc furnace, the landfilling of furnace slag should be reduced: if this slag can be used fully or partially in another industry, it can have a very good impact on the overall environmental performance. Another option is exploring another kind of furnace that produces less slag, however from a life cycle point of view, this cannot be guaranteed to be always true as the other technology might have another drawback in another aspect.
- Higher recycling efficiency and substitution ratios (i.e. quality) for metal scrap are always welcomed.

4. QSE considerations

This section reviews some of the necessary questions to be asked related quality, safety, and environmental (QSE) aspects. Currently, ICRC uses a set of questions and a rating method to assess the QSE appropriateness of its suppliers (QSE Company Assessment Form). This section will not repeat the questions that were already addressed in the form. Nor it provides a comprehensive list of QSE-related questions for all the products.

This section aims to provide the critical questions that need to be asked before selecting a solution from the proposed colored recommendation system. These questions are based on the results of the LCA results and therefore they mainly involve questions around the waste management and disposal, rather than fresh production. The possible or ideal answers are provided. These questions can be added to the current QSE Company Assessment Form, to help ICRC staff evaluate the sustainability of waste management options and assist them in the decision-making process.

Before moving to company assessment, it is recommended that for all waste types, the QSE assessment asks the ICRC staff "*how do you manage the waste?*". Currently, limited information is available about how ICRC deals with different types of waste across different delegations. The answers can sketch a better picture of what happens to garage waste immediately after they are generated. The relevant questions and answers for used oil filters are as follows:

- What recycling technique do you use? What are the processes involved?

Possible answers: Various techniques can be used. The typical processes are shredding, centrifuge for oil separation, iron and aluminum recovery. Some recycling plants only separate oil from filters and shred the filters. Then, they send the cleaned and shredded filters to another facility for metal recovery. Some recycling plants perform the metal recovery too. Moreover, sometimes heating is used instead of centrifuge to evaporate and re-capture the oil.

- What measures do you take to control the emissions from the recycling process?

Ideal answer: The recycling facility should be able to capture oil residue in the oil filters. An oil drain collection must be available in the initial depot area and any subsequent storage. Fume control units or flue gas treatment units are essential for any process involving heating.

- Which materials are recovered and which materials are recovered or wasted at the end of the recycling?

Possible answers: used oil, iron and aluminum scraps, and plastics. Where iron scrap recycling is also done in the same recycling facility, furnace slag is also generated. Used oil must be sent to energy recovery or oil refinery. It shall not be dumped. For metal scraps, the presence of magnetic separator and Eddy Current Separator or similar machines are essential for appropriate recycling. For furnace slags (generated from electric arc furnace if iron scrap recycling is also included), the landfilling should be reduced by reusing the slags in other industries. For plastics and rubber, recycling is preferred over landfilling.

- What source of energy do you use for your recycling process?

Possible answers: If iron scrap and aluminum recycling happen in the same recycling plant, the sources of energy can be renewable energies (highly preferred), natural gas (preferred), light fuel oil (less preferred), and coal (least preferred). If metal recycling is done elsewhere, the source of energy for used oil filter recycling would be electricity only.

- What is the recovery rate and energy efficiency of your recycling process?

Ideal answer: The higher the better. Where several recycling options are available, the options with *higher metal recovery rate* (measured in the form of metal scrap per unit mass of used oil filters), *more efficient energy consumption* (measured in the form of energy consumption per oil filter recycled divided by total energy), and *more robust emission control systems* should be prioritized.

5. Traffic light system recommendations

Used oil filters	**What?**	**When?**	**How?**
Green ***(ideal)***	Recycle	All oil filters at the end of their life	*Recommendations related the recycling plant:* - Conduct a facility visit where possible. The recycling facility should be able to capture oil residue in the oil filters. - The plant should typically follow these processes: *shredding, centrifuge for oil separation, iron and aluminum recovery*. If any of the processes are missing, this means the product related to that process is likely to be landfilled. Special attention should be given to the presence of magnetic separator and Eddy Current Separator (or any non-magnetic separator to separate non-ferrous metals), which are essential for appropriate recycling. - For iron scrap recycling in electric arc furnace after separation from other filter components, the landfilling of furnace slag should be minimized. Instead, the slag can be used in other industries. Iron scrap recycling plants with other kinds of furnace which produce less slag should be prioritized. - The extracted used oil should be sent to energy recovery (e.g., a certified cement kiln) or to oil re-refinery. It shall NOT be sent to landfilling due to hazardousness. Refer to used oil study for details on how to manage used oil.
	Transport	To send used oil filters to recycling plants	Where the recycling plant is located in remote areas, it is recommended to transport used oil filters. Even if the recycling plant is located in a neighbor country more than 1000 km away, it is still environmentally beneficial to send used oil filters, despite the emissions of transportation.
Amber ***(warning)***	Storage	When recycling is not possible	Oil filters must be stored with two containments to avoid leakage. A primary packaging in a leak-proof bag with a tight seal. Large zip-top bags work well for this (can be added to the waste kit). Store the bags in a secondary containment (e.g., a bottom-sealed barrel) away from direct sunlight.
Red ***(no go)***	(Do not) dispose together with other garage wastes	Never	Record the amount of waste, location, and the time for which a red solution has been used and report this information to the HQ.
	(Do not) landfilling or open dump	Never	

CHAPTER 6

Used Lead-Acid Batteries

1. Introduction

Used lead-acid batteries (LABs) are one of the most critical types of waste due to hazardousness and more complex structure, as compared to other garage waste. The prioritization study, presented in chapter 2, identified waste LABs as the second most critical waste generated by ICRC. Based on the survey conducted from ICRC delegations, only around 38% of delegations expressed that LAB waste is properly managed, sold or donated to a certified waste management, whilst 34% stated that they are donated/sold to a waste management company but not sure how it's managed. Considering that the recyclability of LAB is high, as most of the parts after dismantling can be used again to produce new batteries and that batteries also contain precious metals with economic values, usually this kind of waste, when properly managed, is sent to recycling. Therefore, we infer that 72% of ICRC's waste LAB is sent to recycling.

2. Description of the product and waste management

Lead-acid batteries (LABs) are widely used worldwide as energy storage systems in many applications like automotive, uninterruptible power supply (UPS), telecommunication systems and various traction duties depending on the size and shape of the battery. The main advantages of LABs are high unit voltage, low price, possibility of operating at extreme temperatures, and stability of performance (Chang *et al.*, 2009).

Lead-acid batteries consists of electrolyte, lead and lead alloy grid, lead paste, and organics and plastics, which include lots of toxic, hazardous, flammable, explosive substances that can easily exhibit potential risks. The materials contained in lead-acid batteries can cause many pollution accidents such as fires, explosions, poisoning and leaks, contaminating environment and damaging ecosystem. Hence, at their end-of-life, spent LABs have to managed properly to avoid all these risks and recover the valuable materials they contain which can help relieve the pressure from the primary production of these materials. (Zhang *et al.*, 2016).

Recycling of LABs is the default way to go as it is considered a main source of secondary lead worldwide. An average battery (≈14 kg of weight) contains around 80% lead in different forms (e.g., grid, connections, battery paste) in addition to other materials that can be recycled like plastic casing (especially polypropylene), and sulfuric acid after neutralization. In fact, a recycled battery produces only 25% waste (around 20% is hazardous) when compared to a nonrecycled (i.e. produced from just primary resources) battery thanks to recycling lead and plastic, and neutralizing acid (Salomone *et al.*, 2005).

Currently, there are two main techniques for the recovery of lead and lead-containing compounds from LABs: pyrometallurgy and hydrometallurgy. The first obtains metals via high temperature operation, whereas the latter puts more emphasis on the recovery of metals from a solution by using solvents in mild conditions (Li, Liu and Han, 2016).

Pyrometallurgical process has two ways to be carried out. The first is a single step operation, in which both the recovery of the lead via smelting reduction and the desulphurization of the $PbSO_4$ are conducted simultaneously. The other is a two-step operation, in which the $PbSO_4$ in the LABs are first desulphurized, followed by the recovery of the lead from the sulfur-free products via smelting reduction at high temperatures. Similarly, there are two ways to perform recycling of LABs using hydrometallurgical processes. One is the direct solid-phase lead reduction process via electrolysis, in which the alkaline reagents, such as NaOH and Na_2CO_3 are used. The second is indirect lead reduction, i.e. pre-desulphurization and a subsequent electrolytic deposition process in which the lead sulphate in the lead pastes is first desulphurized using $(NH_4)_2CO_3$ or alkali-carbonate as a desulphurizer, whereas the PbO_2 in the lead paste is reduced and transformed into soluble lead compounds (Li, Liu and Han, 2016).

Researchers debate about the environmental concerns of the mostly used pyrometallurgical process despite its simplicity and the high yield of secondary lead preferring hydrometallurgical process as the more environmentally friendly process. However, at the same time it is a slower technique and requires higher investments (Zakiyya, Distya and Ellen, 2018).

3. Review of previous LCA studies

Four seminal LCA studies of lead-acid batteries that are relevant to ICRC’s work are reviewed in this section before conducting an environmental analysis.

3.1. First Study

Salomone *et al.* (2005) applied LCA on a recycling plant in Italy which uses a pyrometallurgical treatment to obtain lead from spent lead-acid batteries. All lead recycling companies in Italy use the pyrometallurgical process according to COBAT (National consortium for spent batteries and leaded waste) (COBAT, 2003).

The recycling plant analyzed is split into three production phases: crushing and hydraulic separation, smelting, and finally refining. Crushing and separation separates out the main components of the battery:

- Plastics: some recyclable plastics are sent to another plastic recycling plant (mainly PP, PE, and PVC),
- Battery pastes and lead grids which go to the next process (i.e., smelting),
- The acid solution which is neutralized using slaked lime giving out water and calcium sulfate.

The plant has almost a closed loop of water, as the water produced from neutralization is used in crushing phase and in smelters cooling. In the smelting process, lead grids and battery paste together with the dusts recovered in the gas circuit of the process, the ashes and the slag generated from the following refining process are smelted using some additives like iron scraps, coke and sodium carbonate. The end products of smelting are unrefined lead and smelting residues. Residues go to waste treatment while the lead goes to the next refining stage.

In the refining process additives can be added to form lead alloys. This process produces high purity lead (≈99%) which can be used directly by battery manufacturers. Another product of this phase is refinery residues which are sent back to smelting as mentioned before. An important aspect here is the environmental control of smelting and refining. There are two separate systems to control emission for each phase. Each system includes scrubbers and bag filters. The bag filters are cleaned periodically, and the dust collected is fed back to the smelters to recover any remaining lead.

A visual description of the analyzed plant can be seen in the figure below. Moreover, the system boundary is illustrated in following figure. The solid boxes indicate the included activities. The environmental credit due to plastic recovery (mainly PP) is accounted for in the overall inventory of the system but the impacts from the plastic recycling plant is not considered (the dotted box). Ancillary materials production means the background systems that produce the materials needed for the recycling of spent batteries.

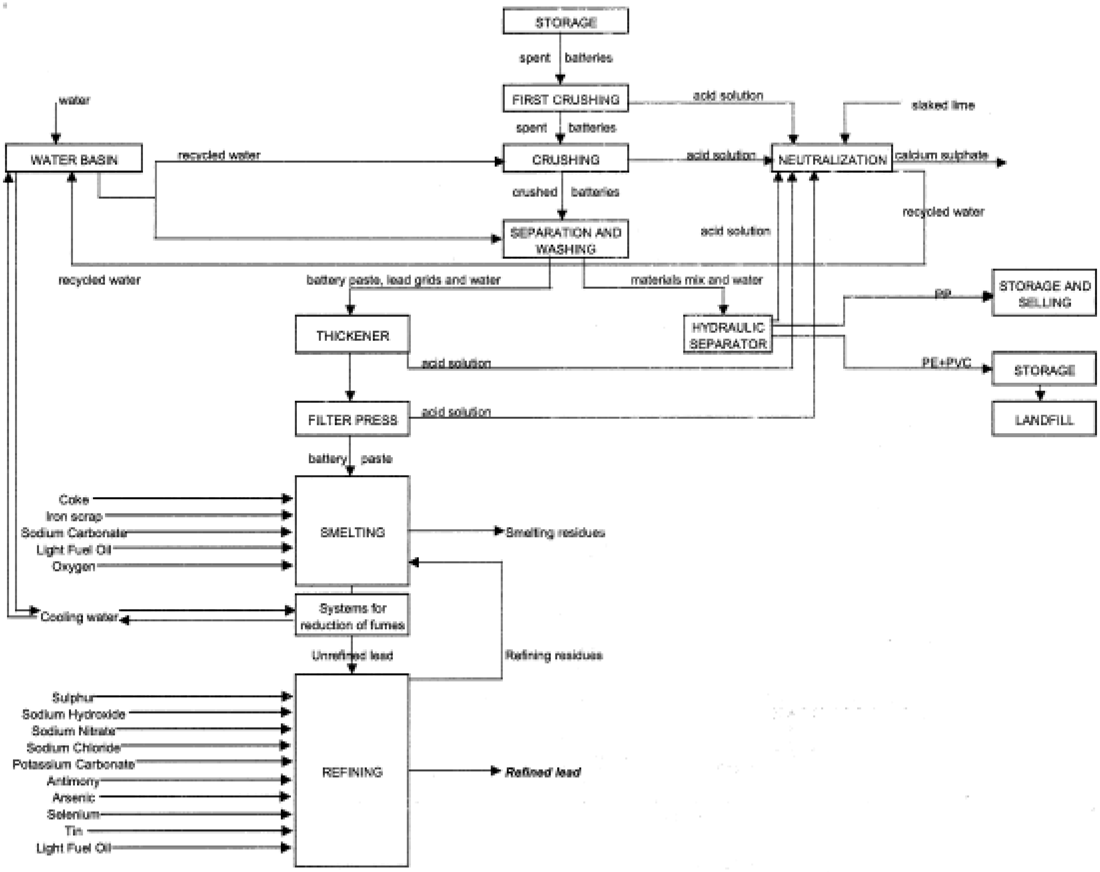

Figure: Recycling plant studied (Salomone et al., 2005)

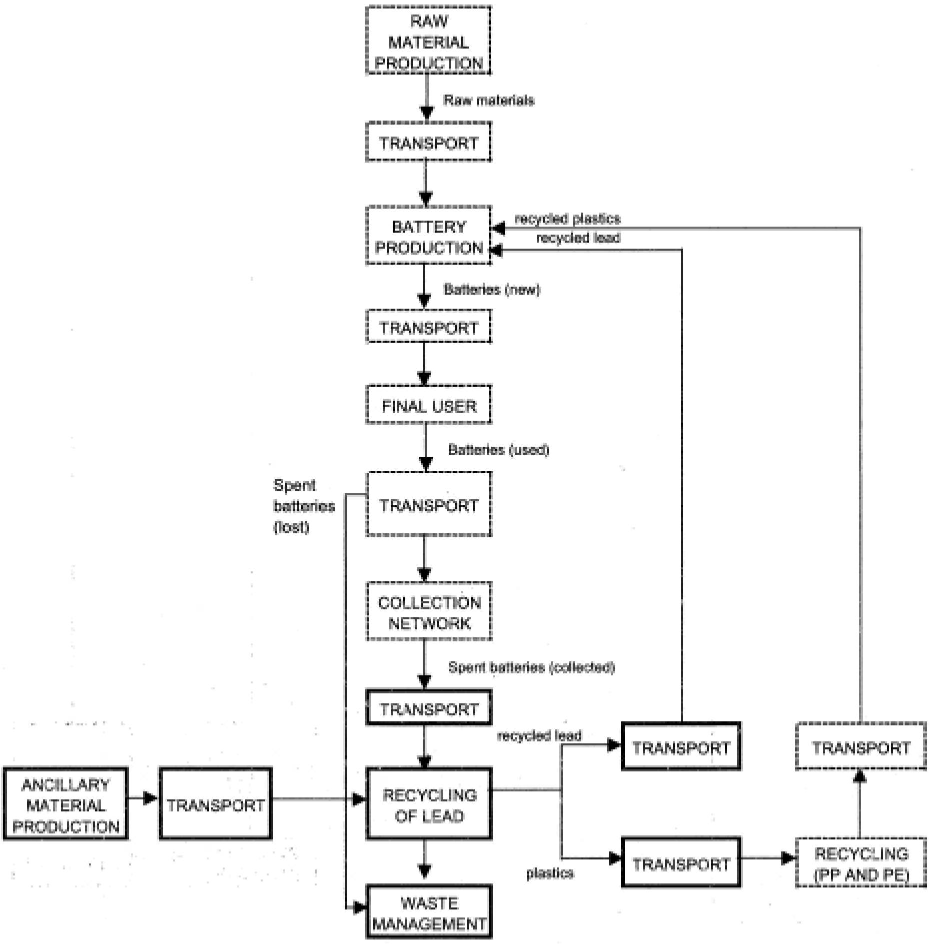

Figure: Lead–acid battery life cycle (Salomone et al., 2005)

The functional unit is one ton of recycled lead delivered to the battery production site. For what concerns the impact categories, the study considered nine impact categories: air acidification, aquatic ecotoxicity, depletion of ozone layer, eutrophication, greenhouse effect, human toxicity, odor (air), photochemical oxidant formation, and terrestrial ecotoxicity. Most of the impact categories are based on CML life cycle impact assessment method (see the annex for more information about the impact assessment methods).

Analyzing the contributions of each phase of the system to the nine impact categories, the smelting stage was found to be the main contributor to all impact categories except terrestrial ecotoxicity, followed by refining. On the other hand, transport, crushing, and neutralization are of minimal contributions. The authors pointed out that the main pollutants associated with smelting and refining are SO_2, CO_2, and NOx but interestingly Pb emissions have insignificant contributions because the plant has a reliable system for total recycling of liquids effluents and for reduction of fumes to decrease the Pb emissions to ground water and atmosphere.

Lastly, Salomone *et al.* (2005) tested changing different parameters of the system in a sensitivity analysis. Overall, the sensitivity analysis indicated that the use of natural gas instead of light fuel oil (used in smelting and refining) has a great positive effect on the system. Moreover, higher energy efficiency in the refining step can improve the overall environmental performance. The authors concluded that emissions of sulfuric acid which often concerns the public communities inhabiting the areas around such recycling plants have no significant environmental problems.

This work in our opinion represents a very well rounded LCA for what concerns spent lead-acid batteries. The detailed inventory extracted from primary data of an existing plant is a strong point and gives reliability to the results. Nevertheless, as any LCA, limitations are always there such as the difficulty of detecting precisely the sulfuric acid and Pb fugitive emissions during crushing.

3.2. Conclusions of the first study

In conclusion the following recommendations can be extracted from this study:

1) Smelting and refining are the hot spots of the system. Hence, focus should be put on improving them.
2) Improvements are mainly energy related. Natural gas is always preferred over other fossil fuels in smelting and refining.
3) Energy efficiency and saving can contribute significantly to reducing environmental impacts of the system.
4) Additional recovery of lead from refining residues is recommended. This can be done by closing the loop as much as possible inside the plant by sending the residues back to smelters to reduce lead losses. Hence generating the least amount of waste with the least amount of lead content.
5) Similarly, smelting residues can contain high percentage of lead. If the recovery of lead from these residues is not possible, it should be sent to a proper waste management plant.
6) Self-sufficiency of water can be achieved if the water from the acid neutralization is reused internally hence saving water resources.
7) Fumes control is crucial for such industry as lead-loaded fumes to air and to soil can cause serious health problems and high level of toxicity in addition to decreasing the overall lead recovery efficiency. Adequate flue gas treatment units must be integrated which should contain filter bags to collect fine particles and dust besides scrubbers to tackle the other potential pollutants (e.g., acidic emissions).

3.3. Second study

Similar studies were conducted in Asia, particularly in China. China contains the largest lead-acid battery industry which currently holds the largest share (45%) of the global LAB market. This makes China a hot spot for the potential environmental consequences of such industry above all lead emissions which is one of the top heavy metals pollutants in China (Sun *et al.*, 2017).

As expected from such enormous production, China generated 33 million tons of used LABs which contains 74% of lead plates for recycling with the potential profits of almost 9.8 billion U.S. (Ma *et al.*, 2018). To analyze the environmental consequences of that industry, Ma *et al.*

(2018) carried out an LCA/LCC (Life Cycle Costing) to assess the environmental impacts and environment-relate costs derived from the LAB industry during the life phases of a starting-lighting-ignition (SLI) LAB which is the one used in internal combustion engines in vehicles. Usage phase was excluded as no data was available and the study was done on plant scale. The included phases are material preparation, battery assembly, transportation, and regeneration (i.e., recycling of spent batteries). The environmental impacts of generating separators and containers during assembly phase were not considered in this study as they are carried out in another plant. The system boundary can be seen in the figure below. Functional unit is 1 KVA h (kilovolt ampere hour).

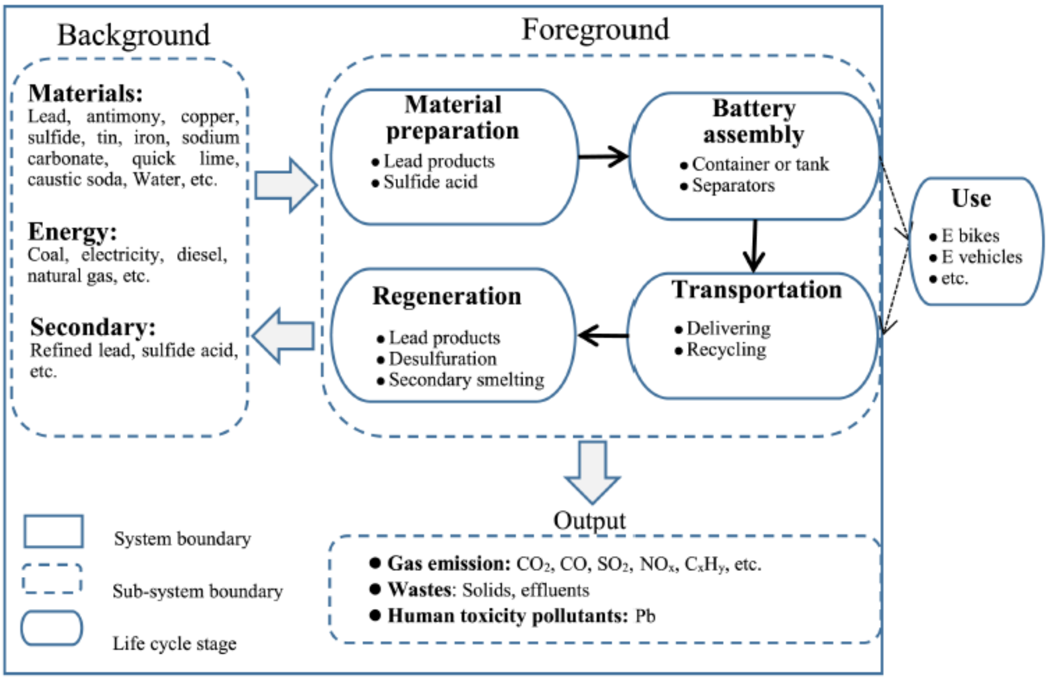

Figure: Life cycle of SLI Lead-Acid Batteries (Ma et al., 2018).

Here we focus on LCA results and the regeneration phase which represents the end-of-life of a LAB. According to Ma *et al.* (2018) investigations, 85% of recycled LABs are used to recover lead, with a recovery rate of around 92% which is very high. The regeneration of spent SLI LABs involves three processes:

1) Crushing and separation process: lead pastes and granules are separated from the mixture of spent sulfuric acid, plastic and rubber.
2) Pretreatment: including purification of spent acid and desulfurization of mixtures to eliminate or at least mitigate the impact of pollutants sourced from crushing and separation (i.e., step 1).
3) Smelting: lead parts and granules are smelted to refine secondary lead.

After recovery of lead, a secondary SLI LAB can be produced. However, with promising chances of lead recovery from spent LABs, the results of the LCA study draws our attention to problematic impacts that can originate from inefficient regeneration. It showed that regeneration phase results in 42.2 g/functional unit of Pb emission (92.5% of the total heavy metal emissions in the entire life cycle) which is around twelve times the amount of Pb emission released per functional unit. in the material preparation phase. The regeneration phase recorded the highest heavy metal emissions impact because of the improper management of lead smelting. The regeneration process was the highest contributor to acidification as well with 55.2% due to desulfurization of spent LABs which takes place at this phase. Regeneration was also responsible for considerable resource depletion due to usage of electricity, coal, natural gas and some materials like iron.

It is noteworthy that apart of the heavy metal emissions from regeneration that can be contained with proper practices of emissions capture and treatment, the material preparation which represents primary LAB production is the first contributor to almost all categories by far. This is an evident indicator to the importance of supporting the recycling industry of LABs while avoiding its drawback simultaneously by adequate practices. By carrying a sensitivity analysis, Ma *et al.* (2018) proved that the heavy metal emission indicator is highly sensitive to the lead recovery rate which means that increasing the recovery rate can significantly compensate the problem of heavy metals emissions from a life cycle point of view. Furthermore, the study here didn't include the materials associated with assembly like polypropylene plastic that represents around 10% of the battery weight (Sullivan and Gaines, 2010; Jülch *et al.*, 2015) which can also be separated and recovered giving more environmental credit to the overall system.

At the end of their paper based on their findings, Ma *et al.* (2018) suggested replacing the energy used in the pyrogenic process of smelting with cleaner energy instead of coal which seems to be the dominant fuel used in their case study. Moreover, they encouraged increasing the lead recovery rate while producing the same capacity of LABs and develop new technologies to reduce Pb emission especially in the end-of life phase.

3.4. Conclusions of the second study

From our side we can summarize the recommendations as follows:

- Choose the highest lead recovery rate while producing the same capacity of LABs (like the brand-new battery). This is a key point, even 1% more in recovery rate is a huge improvement.
- Other smelting processes are preferred over pyrogenic process that uses coal. Try to find another smelting technology that uses electricity from renewables or natural gas.

3.5. Third study

Another study from Thailand done by Premrudee *et al.* (2013) has assessed the life cycle of lead-acid automobile battery manufactured in Thailand given that it is an important automobile industry hub in Asia. They compared conventional batteries with calcium-maintenance free batteries. The system boundary is a cradle to cradle, which means a whole life cycle of a battery from raw material acquisition until disposal which is in this case recycling. The system boundary is shown in the figure below.

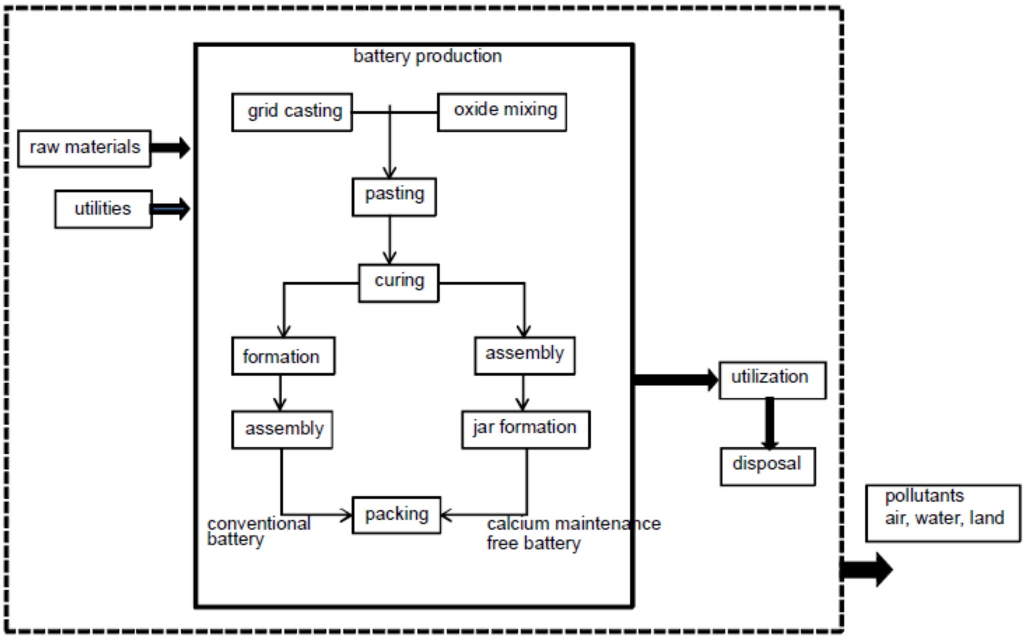

Figure: System boundary including the life cycle of a lead acid battery (Premrudee et al., 2013).

The functional unit is derived from the typical usage period of such batteries which is two years assuming a normal use for a small-size pickup truck. The conventional battery was used over two years, while the calcium-maintenance free battery was used over four years. The maximum capacity measured in A.h is 80 and 90 for conventional and calcium-maintenance free battery respectively. This means that over a period of two years, one conventional battery is used while "half" calcium-maintenance free battery is used given its double lifetime.

Eco-indicator 95 method was used considering five impact categories: global warming, acidification, ozone depletion, heavy metals and energy resources. Impacts were analyzed on mid-point and end-point level. The end-point impacts' indicators were eventually weighted to give a final score following Eco-indicator 95 method.

Results on midpoint level showed that changing from conventional batteries to calcium-maintenance free batteries can reduce environmental impact by 71%, 46%, 60%, 60% and 72% for global warming, ozone layer depletion, acidification, heavy metal release and use of energy resources, respectively. While on the end-point single score level (after weighting), the overall impact can be reduced by 28% if calcium-maintenance free batteries were used. The most relevant impact categories were found to be global warming and acidification with raw material acquisition having the highest environmental impact.

By focusing more on the disposal stage for both types of batteries, Premrudee *et al.* (2013) reported that although all used batteries can be recycled to reduce global warming, acidification and use of energy resources, the recycling process of batteries can have an adverse impact in depletion of ozone layer, and heavy metal releasing to the environment.

On the endpoint however, recycling of conventional batteries and calcium-maintenance free battery could reduce the overall impact score from 0.1079 Pt to 0.0524 Pt, and from 0.0671 Pt to 0.0392 Pt respectively, which is more or less 50% in both cases (figure below).

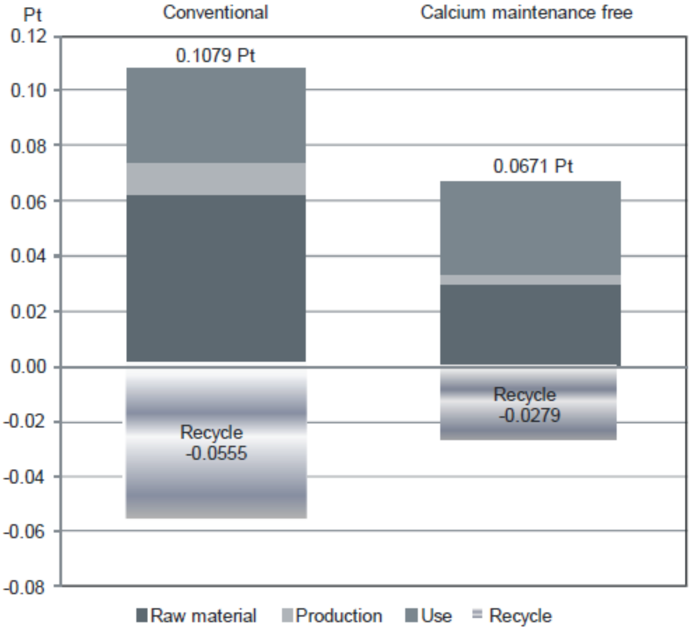

Figure: A comparison of end-point impact for both types of battery based on five impact groups (Premrudee et al., 2013)

Although Premrudee *et al.* (2013) did not focus on the disposal stage nor the details of the recycling process of lead-acid batteries, they concluded that recycling is an important process for greener batteries production. A higher rate of recycling can significantly reduce the environmental impact of such product. The study provided some recommendation to improve and develop lead acid batteries. Using highly recyclable raw materials is important, for example selecting types of plastic polymers that are more manageable (e.g. PP or PE) over less recyclable polymers like PVC or nylon. Moreover, it is recommended to reduce the quantity and types of plastic polymers used in batteries to facilitate the separation of recyclable plastics.

Efforts should be made to develop an adequate battery collection and recycling network and prevent lead from entering the plastic recycling chain. For each battery part after dismantling, a production chain should be established to handle the different parts of the battery after separation. For instance, implementing technologies that can use the acid from old batteries and use it again in new batteries.

3.6. Conclusions of the third study

By looking at the findings of this paper two main recommendations can be drawn:

1) Calcium-maintenance free batteries are environmentally better than conventional lead-acid batteries.

2) Lead-acid batteries is a highly recyclable product, and recycling it is crucial in order to reduce the impacts. Nevertheless, a well-established collection and recycling network is required to achieve the most out of the recycling process given the complexity of the product and the diverse components of which some are toxic (e.g., lead).

3.7. Fourth study

Gao, Hu and Wei (2021) carried out a "gate to gate" study focusing on the production stage of lead-acid batteries again in China. The impact assessment method used is CML2001 and the impact categories considered are abiotic resource depletion, global warming, human toxicity, and acidification. The impacts calculation ends with a normalization step according to the default values in CML2001, so no grouping or weighting was applied. The functional unit is mass based and it is equal to 1 t of lead-acid batteries produced.

According to Gao, Hu and Wei (2021), the production of batteries can be divided into three consecutive phases which are raw material preparation, plate casting, then final assembly and formation. The results showed that the final assembly and formation has the greatest environmental impact in the production of a lead-acid battery. The most influenced impact category of final assembly and formation was found to be abiotic resource depletion because of the formation stage involves a large number of acid injection and battery charging and discharging, hence high consumption of energy. Furthermore, the study stated that the solid waste generated like municipal waste and waste lead slag during the production process can cause adverse environmental burdens. The process is also responsible for the emission of lead dust and lead fumes. Based on their findings, the authors recommended improving the production technology to reduce material and energy consumption. They also highlighted that the recycling of the produced solid waste should be encouraged to achieve cleaner production.

In the same vein, Unterreiner, Jülch and Reith (2016) applied a cradle to cradle LCA on lead-acid batteries focusing on stationary storage system application. They also used the avoided impact concept which considers the recycled material as a credit in the primary material phase. Three types of batteries were compared and one of them is lead acid batteries. The functional unit is calculated based on the expected lifetime of each type of battery, number of cycles per year and energy storage capacity. The chosen functional unit. is 1 useable kWh of capacity (kWh_{uc}). Recipe 2008 method was used to show the results as ecological points (i.e. single score) after the weighting phase. Less points means better environmental performance.

The study tested two recycling scenarios for LAB, one represents the best practice possible and the other represents the state-to-the-art practice. The study showed that the difference between the two approaches is slight based on the percentage of recovered materials with 58% of the materials being reusable in the best-practice scenario compared to 57% which are currently reused. These percentages are much lower than the percentages reported in other studies, nevertheless the different application of the battery might have implied different composition hence lower recyclability.

The results of the study are expressed in the following figure. The hatched part represents the credit the system receives from material reuse thanks to recycling. The use of recycled materials can decrease the ecological points of a LAB up to 49% in the best-practice-scenario. The recycling of lead is the most important factor as it is capable of reducing the impacts of metal depletion and human toxicity during the recycling phase itself. By substituting the current-state scenario with the best-practice scenario a reduction of 12% of ecological points can be fulfilled. This goes in line with the previously discussed study of Ma *et al.* (2018). A small improvement in recovered material from 57% to 58% can result in remarkable environmental benefits for the system.

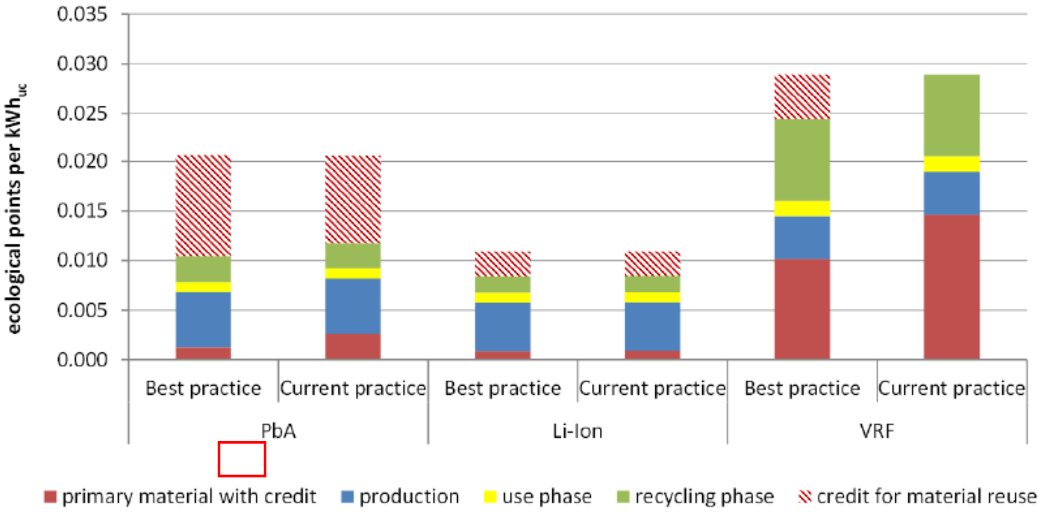

Figure: Ecological Impact of the analyzed battery technologies by lifecycle phase (Unterreiner, Jülch and Reith, 2016)

The paper also pointed out that materials that exist in LABs even in tiny concentrations can affect the overall environmental profile of the system. For example, antimony gives a high impact relatively to its tiny share in the battery's composition (1%) (Sullivan and Gaines, 2010; Jülch *et al.*, 2015).

3.8. Conclusions of the fourth study

What can be concluded here is that:

1) The highest material recovery rate has to be fulfilled.
2) Even the least existing material (e.g. antimony) can have huge benefits if recovered and reused instead of using primary material to produce a new battery.
3) Material reuse thanks to recycling can decrease the environmental impacts of the whole lifecycle (including the recycling process itself) of a LAB by around 50%.

2. LCA on lead-acid battery recycling

2.1. Goal & scope definition

In addition to the literature review of LCA studies, a preliminary LCA study was carried out to provide further insights and facilitating adapting the model to the ICRC context. The system boundary is only representing the end-of-life phase of a lead-acid battery (figure below). The data of the recycling model is obtained from Ecoinvent 3 database. The dataset "*treatment of scrap lead acid battery, remelting RoW*" was used which describes the production of secondary lead outside Europe. The feed of secondary material consists of scrap lead-acid batteries from automotive. The data refers to one big operation in Europe that operates with representative technology that uses a shaft furnace with post combustion, which is the usual technology for secondary smelters. However, as shown in the name of the dataset "*RoW= Rest of the World*", the inventory of the model here represents all the world except Europe which is more realistic for the context where ICRC operates.

Transportation step was added before the recycling phase as the batteries must be moved from ICRC garage to the recycling facility. Furthermore, this is important to test significance of transportation on the overall impact of the system.

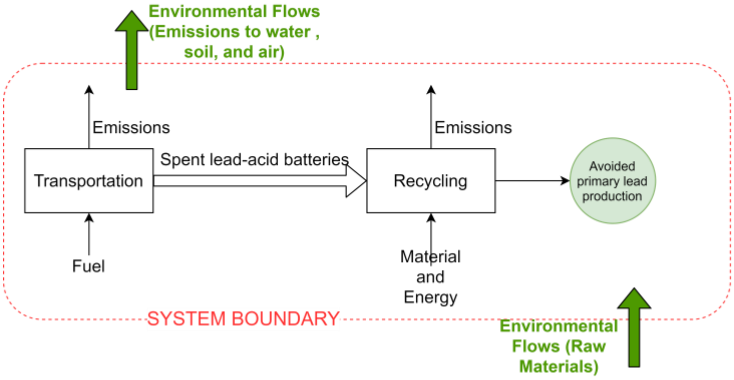

Figure: System boundary of battery recycling.

The functional unit used by the dataset is mass based and not unit based (i.e., per a single battery). The dataset used 1 kg of spent battery. The impact assessment method is ReCiPe 2016 H/H v1.05 (the same as in used oil filters). As it will be shown from the inventory, the recycling dataset here does not represent every single part of the battery that could be recycled. Only the remelting of the main components which are lead-based (e.g., pastes, poles, plates) to recover secondary led was considered. So other minor components like the plastic casing or rubber were not considered. As was the case in the recycling of used oil filters, the system is multifunctional. This was addressed by system expansion to include the avoided impact from lead primary production as shown in the figure above.

2.2. Inventory

The inventory of the dataset “treatment of scrap lead acid battery, remelting RoW” is shown in the following table per 1 kg of scrap lead-acid battery.

Table: Inventory of lead-acid battery treatment: valued given per functional unit (source: dataset of Ecoinvent 3)

Category	Material/energy type	Amount	Unit
Materials (Inputs)	Iron	0.000207	kg
	Lead	-0.64742	kg
	Lime	0.005777	kg
	Sodium Hydroxide	0.174304	kg
	Sodium Sulfate	0.000398	kg
	Sulfur	0.000896	kg
	Sulfuric Acid	4.89E-12	kg
Energy/Fuel (Inputs)	Electricity	0.0351	kWh
	Heat	1.096	MJ
Waste	Nickel slag	0.0438	kg
Direct emissions to air (environmental flows)	Antimony	5.58E-09	kg
	Lead	1.26E-06	kg
	Sulfur dioxide	0.007072	kg

The table shows that the process of smelting has direct emissions to air by itself (i.e. Antimony, Lead, Sulfur dioxide) according to Ecoinvent which was also proven by previous studies. Antimony and lead are highly toxic heavy metals. Another note is the negative sign of lead due to the substitution concept to deal with the recovered lead. The produced lead from the recycling is substituting the production of primary lead. From the table above, for 1 kg of spent batteries, almost 0.65 kg of primary lead production can be avoided. Transportation from ICRC to the recycling plant is modeled with the same dataset used in used oil filters “*Transport, freight, lorry, unspecified {GLO}| market group for transport, freight, lorry, unspecified | Conseq, U*”.

2.3. Impact assessment and interpretation

The impact assessment results are represented in the following table in three common damage categories assuming a transportation distance of 100 km.

Table: Results of LAB recycling model

Damage category	Unit	Total
Human health		
Ecosystems		
Resources		

Note: Since the results of this research will be submitted to an academic journal for publication, the numerical results are not shown in this table.

The results are available upon personal request from the principal investigator, Dr. Hossein Zarei.

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The table demonstrates high benefits from the recycling model indicated by the negative signs in Human Health and Ecosystems. However, the resources damage category is showing a non-negative result even with the material recovery. The contributions of recycling and transportation are shown in the following figure.

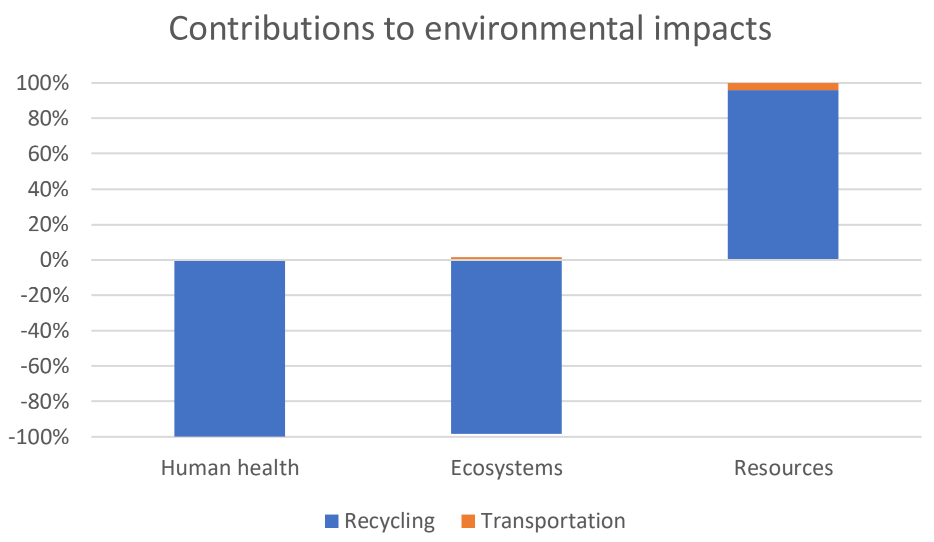

Figure: Contributions of the foreground processes of LAB recycling model

It is evident that the results are mainly influenced by the recycling process. The transportation contribution is negligible. The figure below breaks down the recycling process showing the background sources of impacts.

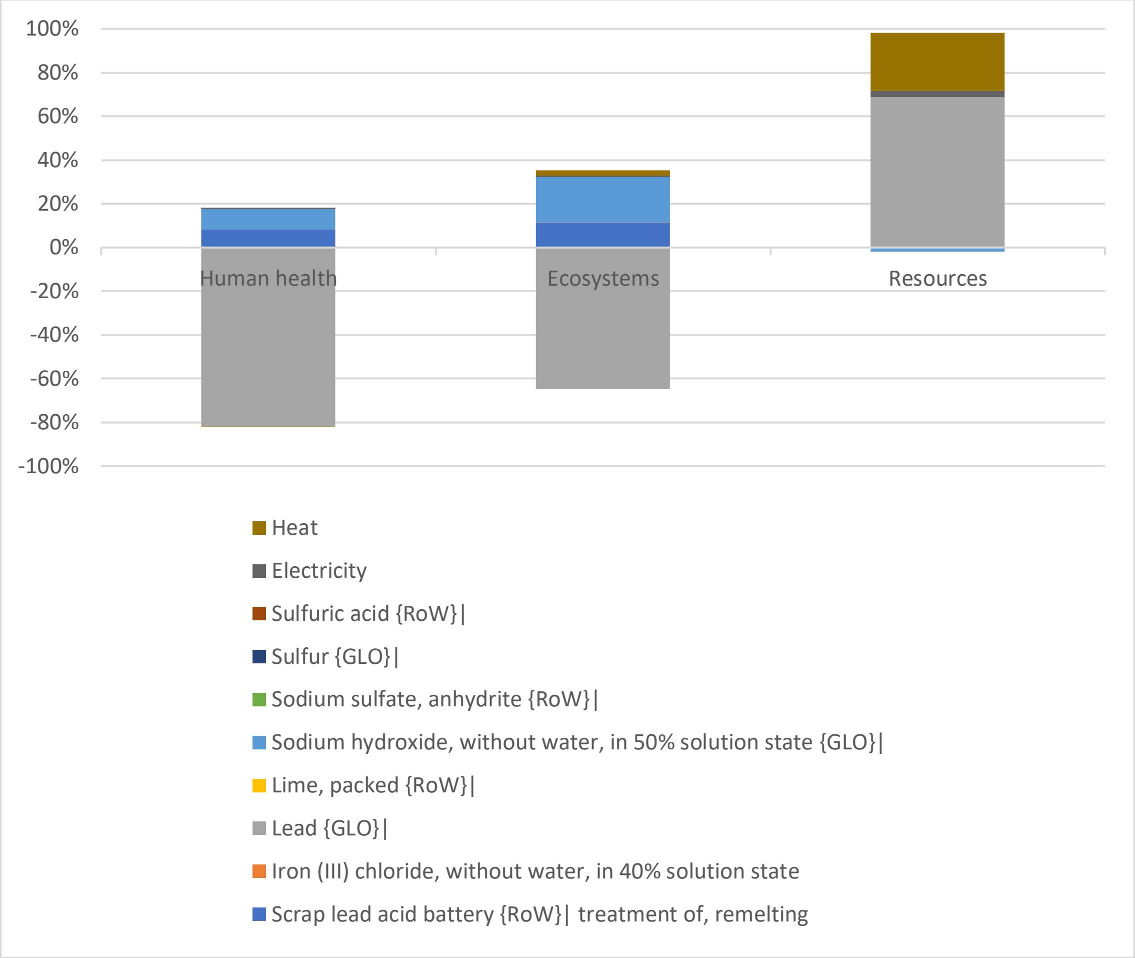

Figure: Recycling Processes background systems contributions

The added impacts (positive sign) in human health and ecosystems are sourced mainly from the production of sodium hydroxide used in smelting, in addition to the direct emissions from the smelting processes itself (i.e., lead, antimony and sulfur dioxide). While obviously the avoided impact is due the secondary lead production as expected.

Nevertheless, in the resources category the highest added impact is due to the avoided lead primary production. This might seem unlogic, but this can be justified by knowing that the primary lead production from concentrate generates a big amount of sulfuric acid. This amount of sulfuric acid will not be produced in case of lead secondary production from spent LABs, so it is a drawback from resources scarcity point of view. The thermal energy (heat) came in the second place to the usage of fuels in the smelting process.

Additional distances were tested for transportation to understand how this can affect the obtained results from the base model. Distances tested are 20, 200, 400, 800, 1000 km. Results showed that transportation has a very slight influence on the overall impacts of the system. The only exception is resources damage category as it was the case in used oil filters model. By increasing the transportation distance from 100 km in the baseline model to 400 km a noticeable increase in resources damage indicator was detected going from 0.0442 to 0.0498, which is around 13% of the baseline result. Overall, it can be concluded from the sensitivity analysis that recycling of lead-acid batteries is encouraged anyway even with high distance transportation. Table below shows the system results for each distance tested.

Table: Effect of transportation distance on the total impacts of LAB recycling system.

Damage category	**Unit**	**20 km**	**100 km (Baseline)**	**200 km**	**400 km**	**800 km**	**1000 km**
Human health	DALY						
Ecosystems	species.yr						
Resources	USD2013						

Note: Since the results of this research will be submitted to an academic journal for publication, the numerical results are not shown in this table.

The results are available upon personal request from the principal investigator, Dr. Hossein Zarei.

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3. Conclusions and recommendations about used LABs management

In this section, recommendations and practical guidelines on spent lead-acid batteries will be listed based on LCA literature review and the LCA conducted in previous section.

- Certified lead-acid battery recyclers are the only way to go. Primitive recycling activities or backyard smelters with no monitoring or environmental certification are to be avoided.
- Until the batteries are transported to the recycler, ultimate care should be given to the storage by ICRC as LABs can represent many kinds of hazards like explosions and leakages of dangerous and toxic substances. Avoid extreme shocks or deformations in the battery casing or seals.
- Recycling in certified smelters is the way to go even if it requires long transportation distances to other remote regions. During transportation, same care as in storage should be given to avoid any accidents. Spent LABs should be loaded on trucks in a way that can absorb any extreme shocks or bumps during the transportation trip.

Given that the pyrometallurgical lead recovery technology is the most researched and the most common, the following guidelines can be given:

- Natural gas is preferred over other fuels like coal and light fuel oil in smelting and refining steps of LAB recycling.
- Focus should be given to the energy efficiency of the recycling facility. For example, compare the energy consumption per battery recycled or per unit mass of secondary lead recovered. Choose the recycler that uses less overall energy per battery recycled or per unit mass of secondary lead recovered at the end.
- The recovery percentage of lead is the second most important part. Higher recovery even the slightest amount is a crucial parameter. With recovery percentage, we mean how much overall secondary lead is produced per unit mass of spent LAB entering the recycling plant (i.e. the yield of the plant). Or it can be referred to the lead mass in the input instead of the overall weight of the battery. The important thing is that recyclers should be compared on the same basis to choose the best option. Any recycling plant

should have documentation that reports this kind of information explaining how this percentage is calculated.

- Recycling facility with refining slag recircuiting system is preferred as it reduces the overall waste of the plant and increase the overall lead recovery.
- The residues of smelters which is inevitable should be made sure that it is sent to a proper waste treatment plant and not disposed into the environment or dealt within an uncontrolled system.
- Check if the water of acid neutralization is reused somehow (better) and not wasted.
- The most important point is the existence of fume control units or flue gas treatment units that should include particulate matter filters (like bag filters or precipitators) to block the lead-contaminated dust from escaping to the environment. This dust should be fed back into smelters to recover any possible extra lead. If not, make sure it is dealt with properly and not disposed in uncontrolled way after being collected from the filters. Furthermore, scrubbers are other units that should exist to deal with emissions like sulfur and nitrogen-based substances that can rise during the recycling activity.
- If possible, the recycling of the other components of the battery like plastics after the battery crushing phase should be a target. Therefore, it is preferred if the recycling facility which takes the task of battery recycling has a good recycling network which includes plastic recyclers for example.
- Make sure that emissions after flue gas treatment units are compliant with local environmental regulations and that audits are done regularly by local authorities responsible for environmental control. This is especially emphasized for lead, antimony, sulfur dioxides.

If the available recycling facilities apply other technologies like hydrometallurgy, it is supposed to be preferred from environmental point of view according to the available literature, however it is not studied enough from environmental aspect. If you have the option to choose between different technologies or different recyclers, always choose the recycler with the highest lead recovery percentage and the cleanest source of energy (natural gas or electricity from renewables) along with the highest energy efficiency, and finally the most robust emissions control system.

4. QSE consideration

This section reviews some of the necessary questions to be asked related quality, safety, and environmental (QSE) aspects. Currently, ICRC uses a set of questions and a rating method to assess the QSE appropriateness of its suppliers (QSE Company Assessment Form). This section will not repeat the questions that were already addressed in the form. Nor it provides a comprehensive list of QSE-related questions for all the products.

This section aims to provide the critical questions that need to be asked before selecting a solution from the proposed colored recommendation system. These questions are based on the results of the LCA results and therefore they mainly involve questions around the waste management and disposal, rather than fresh production. The possible or ideal answers are provided. These questions can be added to the current QSE Company Assessment Form, to help ICRC staff evaluate the sustainability of waste management options and assist them in the decision-making process.

Before moving to company assessment, it is recommended that for all waste types, the QSE assessment asks the ICRC staff "*how do you manage the waste?*". Currently, limited information is available about how ICRC deals with different types of waste across different delegations. The answers can sketch a better picture of what happens to garage waste immediately after they are generated. The relevant questions and answers for used lead-acid batteries are as follows:

- What is the recycling technique used?

Possible answers: Majority of lead-acid recyclers use pyrometallurgy technique. It obtains lead and metals via high temperature operation. Another (newer) method is hydrometallurgy, which recovers lead and metals from a solution by using solvents in mild conditions.

- Which materials are recovered and which materials are wasted at the end of the recycling?

Possible answers: Plastics such as PP, PE, and PVC (ideally, should be sent to another plastic recycling plant), battery paste and lead grids (should be used in recycling processes such as smelting), the acid solution (should be neutralized using slaked lime giving out water and calcium salt), smelting residues (must go to recycling plant, must not be disposed). Recycling facilities with refining slag recircuiting should be prioritized.

- What measures do you take to control the emissions?

Ideal answer: The environmental control of "smelting" and "refining" processes is critical because these are the most impacting processes. Separate control systems are needed for each process. The systems must have scrubbers and flue gas treatment with bag filters or similar dust collecting unit. The bag filters are cleaned periodically, and the dust collected is ideally fed back to the smelters to recover any remaining lead.

- What source of energy do you use for your recycling process?

Possible answers: Renewable energies (highly preferred), natural gas (preferred), light fuel oil (less preferred), and coal (least preferred).

- What is the lead recovery rate of your recycling process?

Ideal answer: The higher, the better, ideally more than 90%. Recyclers with higher lead recovery rate (measured in the form of recovered lead per unit mass of used batteries) should be prioritized.

- What do you do if the acid from the battery spills or leaks? (This question applies to ICRC staff too, if they store any used lead-acid batteries)

Ideal answer: Handle the spilled acid as a hazardous waste because it is corrosive and contains toxic levels of lead. Report all spills that overflow or escape from the storage area to your line manager. Neutralize the acid using cement, lime, or other caustic. Use very dilute lime or caustic since violent reactions can occur. Litmus paper can be used to determine if the acid is neutralized. You may discharge neutralized solutions to the sewer system only if the system connects with the local sewage treatment plant. If a sewer system is not available, the material must be collected and disposed of as hazardous waste. Do not put acid solutions into septic systems or storm sewers. Small quantities of neutralized solids that contain no free liquids may be trashed or taken to a sanitary landfill.

5. Traffic light system recommendations

Lead-acid batteries	**What?**	**When?**	**How?**
Green ***(ideal)***	Replace	When purchasing new batteries or new vehicles	Replace traditional lead-acid batteries with calcium lead-acid batteries. These batteries are greener alternatives and provide operating advantages such as improved resistance to corrosion and lower self-discharge.
	Recycle	Used batteries at the end of their life	Recycle used lead-acid batteries in certified lead-acid batteries recycling plants. If different recycling options are available, always choose the recycler with the *highest percentage of lead recovery*, *highest energy efficiency*, *cleanest source of energy (natural gas or electricity from renewables)*, and finally *the most robust emissions control system.*
	Transport	To send used batteries to recycling plants	Where the recycling plant is located in remote areas, it is recommended to transport used batteries. Even if the recycling plant is located in a neighbor country more than 1000 km away, it is still environmentally beneficial to send used batteries, despite the emissions of transportation. Batteries should be loaded on trucks in a way that can absorb any extreme shocks or bumps during the transportation.
Amber ***(warning)***	Storage	When green recommendations are not possible	Stack batteries in an upright position (no more than four batteries). Ensure the acid will not leak out of the top vent holes. Batteries can be placed on pallets indoors or outdoors. Inspect store batteries weekly for cracks or leaks. For outdoor storage, avoid batteries from freezing as it leads to cracking and leakage. It may also require covering and diking to prevent stormwater contamination. Place cracked and leaking batteries in sturdy, acid-resistant, leakproof sealable containers (can be added to waste kit) and keep the containers closed within the storage area.
Red ***(no go)***	(Do not) dispose together with other garage wastes	Never	Record the amount of waste, location, and the time for which a red solution has been used and report this information to the HQ.
	(Do not) landfilling or open dump	Never	

🟥	(Avoid) primitive recycling activities or backyard smelters with no monitoring or environmental certification	Never	
	(Avoid) extreme shocks or deformations of battery casing or seals during storage or transportation	Never	

CHAPTER 7

Air Conditioner Refrigerant

1. Introduction

From 2018 to 2020, ICRC has used 85 bottles of 13.6 kg R134a as vehicles air conditioner (AC) as well as 10 more units of other types of vehicle refrigerants. Since the majority of refrigerants used by ICRC were R134 type, this light analysis focuses on this type of refrigerant.

According to United States Environmental Protection Agency (EPA)1, R134a is the most common refrigerant used in vehicle air conditioning systems since the 1990s. It is a potent greenhouse gas, that despite not being ozone depleting like R12 (CFC-12), has a considerable global warming potential (GWP), equal to 1,430 CO_2 equivalent. R134a (also known as HFC-134a) is the most abundant HFC in the atmosphere. Usage of R134a in vehicle air conditioning systems accounts for an estimated 24% of total global HFC consumption.

R134a is no longer approved for the use in new light-duty vehicles manufactured or sold in the United States as of model year 2021. However, limited exemptions apply for use of R134a in vehicles destined for use in countries that do not have infrastructure in place for servicing with other acceptable refrigerants. Presumably, the reason for the widespread use of R134a in ICRC vehicles is due to its operating context in such countries.

Figure: A 13.6 kg cylinder of R134a

2. End-of-life environmental impact assessment of R134a

End-of-life environmental impact assessment was conducted on R134a taken from literature and benchmarks from Norway (Baxter et al. 2016)[2]. Two end-of-life pathways were investigated: **recycling scenario** and **waste scenario**. In the recycling scenario, all R134a refrigerants are captured and treated using refrigerant recovery equipment. Next, the refrigerant containers are shredded, and all metals and plastics are recovered, and plastics are used for

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[1] https://www.epa.gov/mvac/refrigerant-transition-environmental-impacts

[2] https://doi.org/10.1016/j.wasman.2016.02.005

thermal decomposition. In the waste scenario, the refrigerants are not captured and instead are allowed to leak into the atmosphere. The metals and plastics are either landfilled or sold to unofficial channels such as to local scrap metal dealers.

The end-of-life analysis was conducted for 0.41 kg of R134a. This is a plausible assumption for the residuals of refrigerants in bottles of 13.6 kg used by ICRC. A transportation distance of about 700 km was considered for collection of AC refrigerants and sending them to a waste treatment (whether it is for recycling scenario or waste scenario). The potential global warming impact for the two scenarios were calculated for 0.41 kg of R134a. The figure below shows the results for the unit of analysis (refrigerator). The stages that impact global warming negatively are shown above the vertical axis while the stages that have benefits are shown below it. The main takeaways from the results are as follows:

- Most of the positive (beneficial) environmental impact arises from the recovered material, including metals and plastics, and energy.

- Most of the negative (detrimental) environmental impact arises during the treatment process in both scenarios. While the amount in recycling scenario is negligible, it is extremely high for the waste scenario.

- The waste scenario emanates a significant negative (detrimental) environmental impact dominated by a single process: emission of R134a during treatment process has the highest negative (detrimental) impact by far (583 kg CO_2 equivalent for 0.41 kg of R134a). This is more than 95% of the total negative (detrimental) impact of all processes combined for this scenario.

- The recycling scenario as a whole is environmentally beneficial and the environmental benefits of recovering materials and energy exceeds the environmental costs of treatment.

- The environmental impact of transportation is insignificant (only 3 kg CO_2 equivalent) in both scenarios despite over 700 km of transportation.

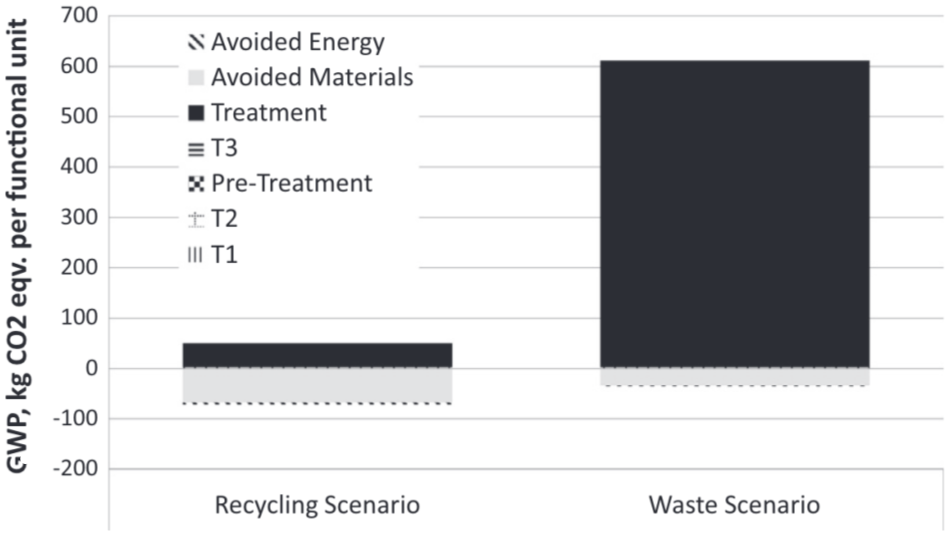

Figure: Global warming benefits and burdens of different processes for the unit of analysis
Source: (Baxter et al. 2016)

3. Recommendations to ICRC

Based on the end-of-life analysis of AC refrigerants, several recommendations could be made to ICRC, as follows.

R1. The first recommendation is to substitute R134a with greener alternatives. This should be initially considered at vehicle procurement stage by ICRC. From 2021, cars manufactured in the US and EU are not allowed to use R134a as AC refrigerant. This can create a positive shift for ICRC to consider greener refrigerants. Currently, there are several refrigerant alternatives approved by EPA that have considerably less GWP and can be used in vehicle air conditioning systems (see table below). While deciding on choosing these alternatives, the procurement team should consider the availability of infrastructure for air conditioning services in the countries ICRC operate.

Table: Comparing R134a against greener alternatives

Refrigerant	Description	GWP
R134a	Currently being widely used in ICRC vehicle air conditioning systems but is no longer approved for new cars manufactured from 2021.	1,430
R152a	R152a is a refrigerant that is not currently being used widely in vehicle air conditioning systems but may be pursued in the future. R152a is flammable but can be used safely.	124
R1234yf	R1234yf is a refrigerant being introduced by many automobile manufacturers. There are already cars on the road using this alternative. R1234yf is mildly flammable but can be used safely.	4
R744 (CO_2)	CO_2 is a high-pressure refrigerant being considered by automobile manufacturers. CO_2 systems operate at 5 to 10 times higher pressure than other vehicle air conditioning systems. It contains the lowest GWP amongst alternatives.	1

R2. Where infrastructure for servicing greener alternatives is available, it is possible to change the refrigerant used in current ICRC vehicles from R134a to greener alternatives such as R1234yf. This, however, requires practical know-how to ensure compatibility of lubricant, seal, and valves for the transition.

R3. ICRC should purchase AC refrigerants from suppliers that offer take back schemes, where possible. Through these schemes, the suppliers accept receiving empty bottles of refrigerants and commits to recycling them in an environmentally friendly manner approved.

R4. For current AC refrigerant waste, the most environmental-friendly solution is to capture the residual refrigerants in containers and then recycle the metals and plastics. Equipment for capturing refrigerants can be purchased at a reasonable price and utilized at ICRC delegations. The equipment can be added to “ICRC waste kit” in delegations with high amounts of AC refrigerant waste.

They can also be sent from one delegation to another as they are light-weight equipment (around 15 kg). Since the equipment moves from one delegation to another, and not the captured gas, this would not create an issue on cross-border transportation. The economic value generated from the sales of captured gas can return the investment on such equipment. An example is shown in the following figure, being sold on the UK market for around £937.

Figure: Example of refrigerant recovery machine

Source: BES UK

It would be helpful for ICRC to set a moving target for capturing refrigerant residuals for the years to come. In a developed country such as Norway, it is estimated that 75% of AC refrigerants in the electronic waste are recovered. ICRC can target recovering 40% of the refrigerants in garage waste in the first year, adding 10% to this target for each year afterward. Efforts should initiate from ICRC delegations with the highest wastage of AC refrigerants.

Once the refrigerants are captured, different options are available to choose from. They can be:

- Reused in ICRC vehicles.
- Sold to a certified reclaimer.
- Sent to a destruction facility.
- Stored safely, until being reused or sold (as shown in the following figure).
- However, cannot be sold as new.

Since the captured gas has immediate use, it may not be regarded as a “waste”. Due to versatility of uses available for captured gas, it would most likely be reused or sold in the country of capture and cross-border transportation would not be required. If chosen to be sent for destruction, they can be used for liquid injection incineration, rotary kiln incineration, or cement kiln.

Figure: R134a residuals captured from waste containers and safely stored

Source: EPA guidelines on construction and demolition of refrigerants

R5. It is essential that R134a is handled properly during capturing process to prevent leakage. Leakage of even small amounts can negate the benefits of the whole recovery process. In the benchmark example presented in section 2, if only 50 grams (out of 400 grams considered in the study) of R134a is allowed to leak to atmosphere, all the benefits from the whole value chain are compromised. Using certified equipment and technical training are the key in preventing leakage during the process.

R6. Where capturing AC refrigerants is not an option, "null" option (that of doing nothing) should be taken. Storing AC refrigerant empty containers is an acceptable option from environmental point of view and does not pose considerable environmental risks or impacts. Null option strongly outweighs scrapping without capturing refrigerant residuals or giving the waste to local population, which eventually results in venting of refrigerants to the atmosphere. All possible measures should be taken to avoid leakage.

4. QSE considerations

This section reviews some of the necessary questions to be asked related quality, safety, and environmental (QSE) aspects. Currently, ICRC uses a set of questions and a rating method to assess the QSE appropriateness of its suppliers (QSE Company Assessment Form). This section will not repeat the questions that were already addressed in the form. Nor it provides a comprehensive list of QSE-related questions for all the products.

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Before moving to company assessment, it is recommended that for all waste types, the QSE assessment asks the ICRC staff "*how do you manage the waste?*". Currently, limited information is available about how ICRC deals with different types of waste across different delegations. The answers can sketch a better picture of what happens to garage waste immediately after they are generated. The relevant questions and answers for AC refrigerants are as follows:

- How do you manage empty R134a containers?

Possible answers: Capturing the gas and recycling the metal and plastic (most preferred), capturing the gas and disposing metal and plastic (less preferred), disposing the container with the rest of waste (must be avoided).

- What percentage of the gas leaks during the capture process?

Ideal answers: ideally zero. Leakage of even small amounts is hazardous and has significant environmental impact.

5. Traffic light system recommendations

AC Refrigerant	**What?**	**When?**	**How?**
Green ***(ideal)***	Substitute R134a with greener alternatives	At vehicle procurement stage	Purchase vehicles that run on greener AC refrigerants such as R1234yf.
	Change the refrigerant used in current ICRC vehicles from R134a to greener alternatives	For current fleet running on R134a	Experienced technicians required to ensure compatibility of lubricant, seal, and valves.
	Purchase R134a from suppliers that offer take back schemes	When refill for AC refrigerant of current fleet is needed	Scout for suppliers that accept receiving empty containers of AC refrigerants and commit to recycling them.
	Recycle R134a	When dealing with R134a empty containers	- Capture the residual refrigerants in containers and then recycle the metals and plastics. - Use refrigerant recovery machine for capturing refrigerants. Add these machines to waste management kits. - Handle the gas properly during capturing process to prevent leakage.
	Reuse or sell the captured R134a	When residual gas in empty containers is captured	Reuse the captured R134a in current fleet or sell it to certified reclaimer.
Amber ***(warning)***	Store AC refrigerant empty containers	When green recommendations are not possible.	Store outdoors (not under direct sunlight) or indoors with good ventilation.
Red ***(no go)***	(Do not) scrap or landfill empty containers without capturing AC refrigerant residuals	Never	Record the amount of waste, location, and the time for which a red solution has been used and report this information to the HQ.
	(Do not) give the empty containers to local population	Never	

CHAPTER 8

Used Tires

1. Introduction

From 2018 to 2020, ICRC has generated nearly 17,400 used tires across all its delegations. Approximately 3 billion tires are disposed every year and the number is expected to reach 5 billion by 2030[3]. Recovery options are available at industrial scale and 70% of used tires are being recovered worldwide. However, this number is much lower in developing and less developed countries[4], where most of used tires are landfilled or burnt, posing serious health and environmental issues.

Figure: A large tire graveyard in Kuwait

This analysis excluded obsolete disposal methods including landfilling and burning in open air as these methods have shown to have significant negative environmental and health risks. Instead, it identifies and compares major recovery methods and proposes recommendations on most environmentally friendly options.

2. End-of-life environmental impact assessment of tires

Used tires have versatile end-of-life options: they can be re-treaded, recycled to be used for a variety of purposes, or used to produce energy for example in cement kilns. In this analysis adapted from Clauzade et al. (2010)[5], 9 common end-of-life scenarios are compared. These

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[3] https://www.mdpi.com/1996-1073/14/3/571
[4] https://www.tandfonline.com/doi/full/10.1080/10962247.2017.1279696
[5] https://link.springer.com/article/10.1007/s11367-010-0224-z

scenarios range from energy recovery applications such as steel production, cement production, and foundries to material recovery and recycling options such as artificial grass and moulded objects. The 9 scenarios are as follows.

- *Steelwork production*

- *Foundries*

- *Cement production*

- *Urban heating*

- *Moulded objects*

- *Synthetic turfs* (artificial lawn)

- *Equestrian floors* (horse floor mats)

- *Retention basins* (an artificial pond used to manage stormwater runoff to prevent flooding and soil erosion)

- *Infiltration basins* (the same as retention basins, except they infiltrate the water gradually into the ground)

Each of these scenarios "replace" a traditional method. For example, using used tires to produce energy in urban heating and cement production replace using coal to produce energy for the same purpose. The following table depicts the traditional method which is assumed to be replaced by each of the 9 scenarios.

Table: The recovery scenarios studied, and products replaced

Recovery scenario	**"Traditional" method replaced**
Steelwork production	Anthracite and scrap metal
Foundries	Foundry coke and scrap metal
Cement works	Petroleum coke and coal
Moulded objects	Anti-vibration mats made of virgin polyurethane
Synthetic turfs	Synthetic turf made of virgin EPDM and chalk
Equestrian floors	Equestrian floors made of sand
Urban heating	Coal
Retention basins	Retention basins made of blocks of concrete and polyethylene blocks
Infiltration basins	Infiltration basins made from gravel

In all scenarios, first, used tires were stored and accumulated in a depot. Then, they are collected and sorted. Those tires that pass required tests and are part worn are sent for retreating. The rest of tires are sent to recycling/incineration plant to be used in creating new products or to generate energy. Road transport of 50-100 km distances were considered. The functional unit was "recovering one ton of used end-of-life tires from a collection point". The results of global warming benefits and burdens of different scenarios for the unit of analysis are shown in figure 6.

It is noteworthy that eight environmental indicators related to water, soil, and air (e.g., water consumption, acidifying gas, tropospheric ozone, etc.) are considered in the study, but only one indicator (greenhouse effect) is depicted in the figure below. Moreover, it is important to note that if the traditional replacement methods (as listed in the table above) change, this would impact the avoided impact and the results of the study.

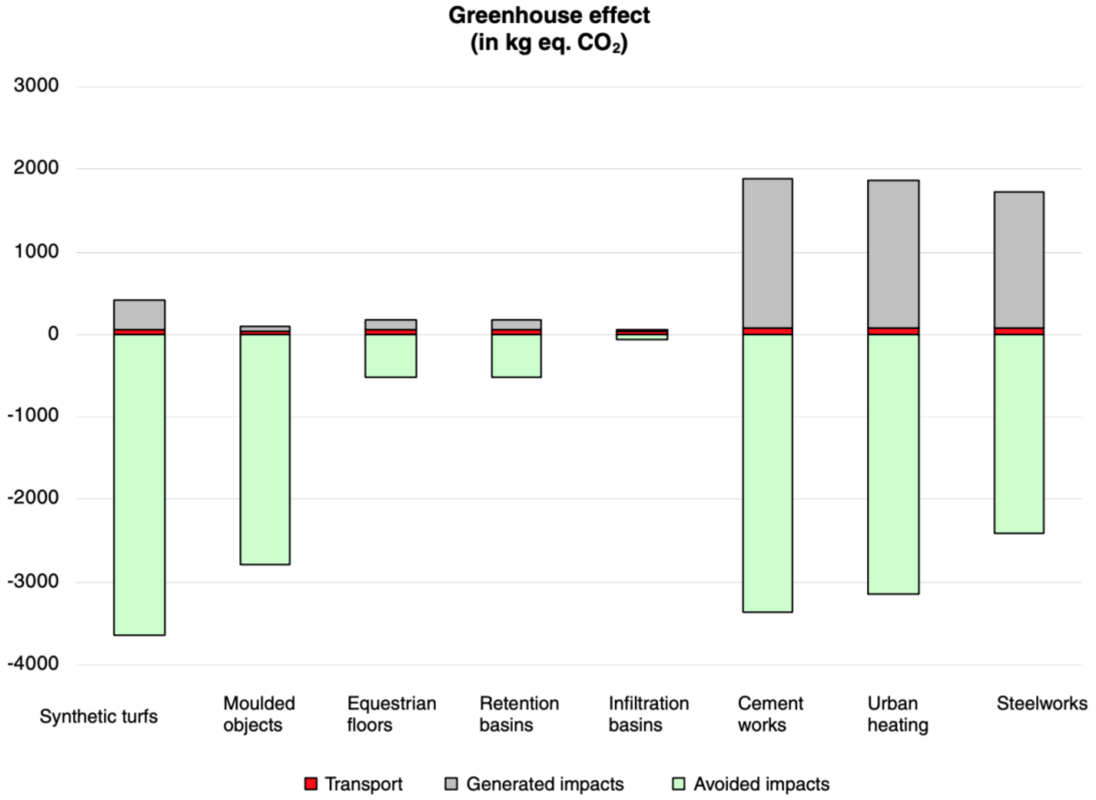

Figure: Global warming benefits and burdens of different recovery scenarios for used tires

Source: Clauzade et al. 2010

The green bars in the above figure denote avoided impact. That is the negative impact that is avoided due to replacing the traditional method with the recovery scenario (see the table above). The main conclusions from the environmental assessment are as follows.

- All the scenarios provide significant environmental benefits for all environmental indicators. This means that no matter used tires are used to generate energy in a cement kiln or recycled to create molded rubber objects, all these scenarios are environmentally sustainable and outweigh traditional methods.

- Among the studied scenarios, incineration of whole tires in cement plants, production of synthetic turf, and manufacturing of molded objects are shown to be the most beneficial methods.

- Counterintuitively, recycling used tire is not always preferred over incineration to produce energy.
- The impact of transportation was found negligible, even for longer distances.

3. Recommendation to ICRC

Based on the end-of-life analysis of used tires, several recommendations could be made to ICRC, as follows.

R1. The first recommendation is to avoid landfilling and dumping tires due to several risks they pose. First, although used tires are ostensibly more inert garage waste, as compared to other items such as used oil, landfilling them poses considerable risk of fire. In May 2016, a fire in one of the largest landfills in Europe, located in Seseña, Toledo, Spain, burnt 70,000–90,000 tons of tires which were illegally accumulated for more than 15 years. The evidence[6] shows higher cancer levels in human in adjacent areas of the landfill and sever contamination of air, soil, and crops.

Second, open landfilling increases the risk of scavenging and illicit secondary uses. In less developed countries and countries with humanitarian situation, they may be used by local population directly on their vehicles. Another widespread secondary use is tire illegal oil extraction, which is prevalent in developing countries[7]. In this process, tires are heated until melted and low-quality oil is extracted. The remaining substance, such as carbon residue and liquid fuel, is then dumped without recycling causing serious soil and water pollution. The collected oil is sold as fuel oil.

R2. For half-worn tires, which still have some working life remained but are not suitable for ICRC use, it is recommended that ICRC does not give these tires to local population, mainly due to reputational reasons and partly due to environmental reasons. Several years ago, ICRC received bad publicity when a car accident happened due to a fault in a tire that was given to locals by ICRC. On the environmental side, accumulating these used tires would increase the number of tires and consequently the attractiveness of ICRC's used tires for legal recyclers.

R3. The most preferred option for used tires is retreading. It is the most resource-efficient strategy saving rubber, iron, and petroleum resources. Whether done manually at a local workshop or in an advanced retreading facility, it involves negligible environmental impact and gives new life to used tires. The drawback is lower quality of retreaded tires, as compared to new tires. Yet, it is a favorable option both economically (due to low-cost operations), environmentally (negligible negative impact), and socially (job creation for local population).

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[6] https://www.sciencedirect.com/science/article/pii/S016041201630383X
[7] https://www.sciencedirect.com/science/article/pii/S0956053X10003211

This is specifically interesting for truck and SUV tires where tires are often retreaded three to four times.

R4. Those tires that are not suitable for retreading should be used for material recovery (e.g., rubber recycling) or energy recovery (e.g., cement manufacturing). Although the environmental impact of different material and energy recovery methods vary, based on the comparative study presented before and supported by literature, all the material and energy recovery methods are environmentally sound. It is recommended that ICRC chooses the recovery method based on the availability of recovery methods. Attention should be given to recovery plant's environmental certificate and functioning chimney filters.

Figure: Material recovery from used tires

Source: Ferdous et al. (2021)[8]

R5. Incineration of used tires for cement manufacturing or urban heating, if done properly, can be equally favourable to material recycling. This holds specifically valid in less developed contexts where coal is originally used for cement manufacturing or urban heating.

R6. In the absence of any recovery options (incineration or recycling), the last measure would be shredding the tires and storing the shredded rubber in heavy duty sacks. This reduces the space needed for storing used tires and reduces the risk of fire, until an incineration or recycling option becomes available. Local shredders' capacity can be used for this purpose.

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[8] https://www.sciencedirect.com/science/article/pii/S0921344921003542

Figure: Shredded rubber from used tires stored in sacks

R7. Innovative solutions should be considered, where possible. A variety of innovative solutions are available for used tires: sports grounds, playground equipment, sports and house matts, insulation, sound proofing, anti-vibration support, retaining walls, and retention basins. This video from Aliapur, a large French tire recycler, presents versatile uses of used tires. This project in India, using used tires to make playground for children in disadvantaged areas is another example of innovative solutions. These solutions are considered safe for human and children health.

(a) Asphalt mix with crumb rubber [19]

(b) Waste tyres for retaining wall [110]

(c) Composite panel system using tyres

(d) Railway sleepers from waste tyres [114]

(e) Roofing system using waste tyres [112]

(f) Well-paved road using waste tyres [113]

Figure: Innovative uses of used tires

R8. Finally, the environmental impact of transport is negligible, and it is recommended to transport used tire even to longer distances where a recovery solution is available.

4. QSE recommendations

This section reviews some of the necessary questions to be asked related quality, safety, and environmental (QSE) aspects. Currently, ICRC uses a set of questions and a rating method to assess the QSE appropriateness of its suppliers (QSE Company Assessment Form). This section will not repeat the questions that were already addressed in the form. Nor it provides a comprehensive list of QSE-related questions for all the products.

This section aims to provide the critical questions that need to be asked before selecting a solution from the proposed colored recommendation system. These questions are based on the results of the LCA results and therefore they mainly involve questions around the waste management and disposal, rather than fresh production. The possible or ideal answers are provided. These questions can be added to the current QSE Company Assessment Form, to help ICRC staff evaluate the sustainability of waste management options and assist them in the decision-making process.

Before moving to company assessment, it is recommended that for all waste types, the QSE assessment asks the ICRC staff "*how do you manage the waste?*". Currently, limited information is available about how ICRC deals with different types of waste across different delegations. The answers can sketch a better picture of what happens to garage waste immediately after they are generated. The relevant questions and answers for used tires are as follows:

- For incineration and energy recovery from used tires, what measures do you take to control the emissions?

Ideal answer: The environmental control of incineration process is critical. The fume controls and chimneys must have scrubbers and flue gas treatment with bag filters as well as activated carbon. Using activated carbon is important as the incineration of rubber produces dioxin, which can be removed by the addition of activated carbon. All filters and scrubbers should be cleaned periodically.

- What measures do you take for storage of used tires or shredded tires?

Ideal answer: Any storage of used tires or shredded tires must account for fire risk. Fire extinguishers and fire alarms must be present. Distance must be kept between tire storage areas and working areas.

5. Traffic light system recommendations

Used tires	**What?**	**When?**	**How?**
Green ***(ideal)***	Retread	For used tires with some life left	Give to local or advanced retreading facilities, especially for SUV and truck tires.
	Transport	For any type of used tire when transportation is needed	Transport used tires to recycling plant, retreading facility, incineration (e.g., cement plant or urban heating), or to construction companies, even if these facilities are located in long road distances and a cross-border transportation is needed.
	- Recycle for material recovery - Controlled incineration for energy recovery	For used tires at the end of their life	Choose any recovery method that is available, for example, sending to a recycling plant or controlled incineration in cement kiln or urban heating. Ensure that the recycling / recovery facility has robust emissions control system and, ideally, is environmentally certificated.
	- Use in construction	For used tires at the end of their life	- Give to construction companies to be used for construction purposes such as asphalt mix, roofing, sports grounds, playground equipment, sports matts, insulation, sound proofing, anti-vibration support, etc. - Partner with NGOs and local authorities to use used tires in children's playgrounds or other innovative uses. This has a positive social impact by creating jobs as well as providing facilities for children.
Amber ***(warning)***	Shred and store	When green recommendations are not possible.	Shred the used tires and store the shredded rubber in heavy duty sacks to avoid the risk of fire until a green solution is found. Use third-party or local shredders.
Red ***(no go)***	(Do not) landfilling used tires.	Never	Record the amount of waste, location, and the time for which a red solution has been used and report this information to the HQ.
	(Do not) burn in open air.	Never	
	(Do not) give to uncertified recyclers / local population for recycling, oil extraction, or secondary use.	Never	

CHAPTER 9

Used Glass

1. Introduction

From 2018 to 2020, ICRC garages generated nearly 1,100 windshields and car door glass waste across all its delegations. A car typically contains 15.6 – 36.6 kg of glass which constitute around 3 per cent of total vehicle mass[9].

2. Environmental considerations of used automotive glass

European Commission's directive on end-of-life vehicles[10] recommends dismantling and recycling glass as the most environmentally friendly end-of-life option. Glass is 100% recyclable and can be recycled infinitely with no loss of quality. Glass recycling is not energy-intensive, and the recycling processes are well-developed. However, around 75% of glass goes to landfill[11]. The reason for landfilling glass is mainly due to low economic value of glass. The estimated value of all glass waste from a vehicle at the end of its life is 0.5 Euros[12].

Two general scenarios are considered for the end of life of glass. First, automotive glass is separated and shredded. Then, 65% of the glass is cleaned and recycled as new glass and the rest goes to landfill. Second, after separation and shredding, all the glass is used as construction material. The following figure compares the CO_2 emissions of both scenarios for "1 kg of automotive glass waste" as the functional unit.

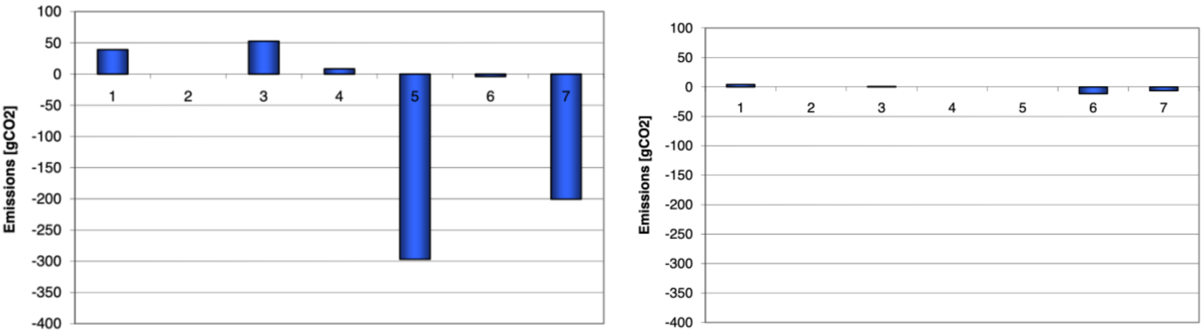

Figure: CO_2 emissions for the end of life of automotive glass

Left: 65% of the glass is recycled. Right: All the glass is used as construction material.

1) Transports, (2) Dismantling, (3) Shredding & Separation, (4) Cleaning, (5) New glass products, (6) Construction material, (7) Total

Source: Lassesson (2008)[13]

The figure shows the CO_2 emissions for both scenarios. Although the first scenario (shown on the left) shows higher levels of CO_2 emission from the process of glass production, it is offset

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[9] https://www.sciencedirect.com/science/article/pii/S0959652616000512

[10] https://ec.europa.eu/environment/topics/waste-and-recycling/end-life-vehicles_en

[11] https://www.sciencedirect.com/science/article/pii/S0921344921003542

[12] https://www.mdpi.com/2071-1050/12/21/8764

[13] https://odr.chalmers.se/bitstream/20.500.12380/185110/1/185110.pdf

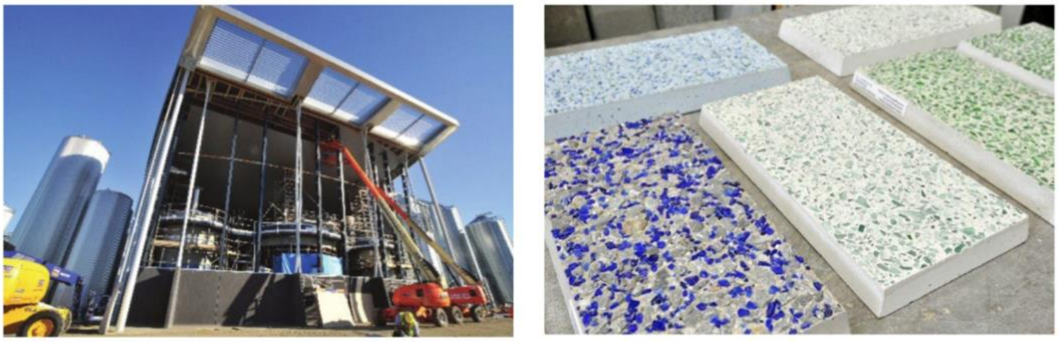
by the emissions of glass production from virgin material (avoided impact). This means the recycling process is justified because it avoids CO_2 emissions from the glass production with virgin material.

3. Recommendation to ICRC

There are two main options at the end of life of automotive glass: recycling and landfilling. The following recommendations show how ICRC can best deal with automotive glass at the end of its life.

R1. The most environmentally friendly option for automotive glass at the end of its life is recycling. For recycling facilities, it is recommended that ICRC ensures that the furnace is correctly equipped with flue gas abatement line.

R2. Where recycling is not possible, glass can be crushed and used for construction. The shredded glass has a variety of uses in construction, to reinforce concrete or to be used in asphalt pavement, for example. The figure below shows some of the uses of glass waste in construction.



(a) Glass used in building concrete structure (b) Architectural concrete using waste glass

(c) Permeable pavement using waste glass (d) Recycled glass used in road construction

Figure: Use of glass waste in construction sector

R3. Where recycling or shredding are not available, automotive glass waste can be safely landfilled. Under EU law, glass is considered inert and would not contaminate the environment if landfilled. Therefore, ICRC can safely landfill automotive glass waste as a non-hazardous waste material.

R4. Finally, glass is heavy and expensive to transport over long distances. In the absence of local recyclers, ICRC can safely landfill glass waste if long-haul (e.g., cross border) transportation is impractical or costly.

4. QSE Considerations

This section reviews some of the necessary questions to be asked related quality, safety, and environmental (QSE) aspects. Currently, ICRC uses a set of questions and a rating method to assess the QSE appropriateness of its suppliers (QSE Company Assessment Form). This section will not repeat the questions that were already addressed in the form. Nor it provides a comprehensive list of QSE-related questions for all the products.

This section aims to provide the critical questions that need to be asked before selecting a solution from the proposed colored recommendation system. These questions are based on the results of the LCA results and therefore they mainly involve questions around the waste management and disposal, rather than fresh production. The possible or ideal answers are provided. These questions can be added to the current QSE Company Assessment Form, to help ICRC staff evaluate the sustainability of waste management options and assist them in the decision-making process.

Before moving to company assessment, it is recommended that for all waste types, the QSE assessment asks the ICRC staff "*how do you manage the waste?*". Currently, limited information is available about how ICRC deals with different types of waste across different delegations. The answers can sketch a better picture of what happens to garage waste immediately after they are generated. The relevant questions and answers for used glass are as follows:

- For glass recycling, what measures do you take to control the emissions?

Ideal answer: The fume controls and chimneys must be equipped with flue gas abatement line and chimney control.

5. Traffic light system recommendations

Glass waste	**What?**	**When?**	**How?**
Green ***(ideal)***	Recycle	For any automotive glass at the end of its life	- Ensure the furnace in the recycling plant is correctly equipped with flue gas abatement line and chimney control. - Check for any environmental certification of the recycling plant.
	Use in construction	For any automotive glass at the end of its life	- Waste glass can be shredded or crushed, and then used for a variety of construction purposes such as concrete reinforcement or road construction. - No environmental checks are required for glass crushers.
Amber ***(warning)***	Landfill	When recycling or use in construction is not possible	- Landfill in an urban or approved landfill site. - If long-haul road transports to recycling plant is not feasible, landfilling can be selected as the waste management option.
Red ***(no go)***	Open dumping	Never	Record the amount of waste, location, and the time for which a red solution has been used and report this information to the HQ.

CHAPTER 10

Making Sound Waste Management Decisions

1. Decision making on waste management

This report aimed at providing ICRC with clear, concise, and structured recommendations to deal with garage waste. In reality, different situations, not covered in this report, might arise. ICRC staff should be trained to have basic knowledge to make decisions on waste management in emergency situations.

One of the basic and straightforward concepts that can be used for decision making is European Union Waste Framework Directive, as shown in the following figure. The framework shows different waste management options based on their preferences.

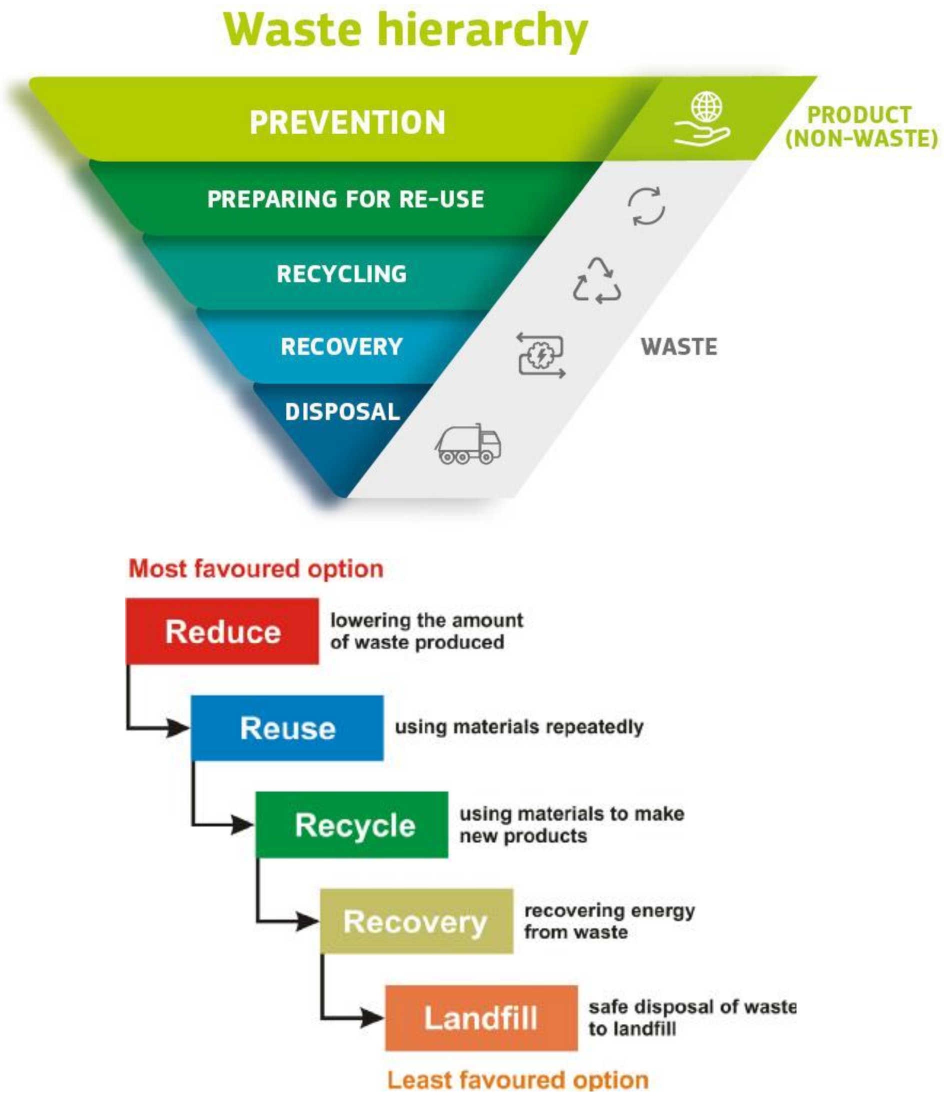


Figure: EU Waste Framework Directive

Source: https://ec.europa.eu/environment/topics/waste-and-recycling/waste-framework-directive_en

In the following, the framework and the way to utilize it are described by way of example. They can be used for ICRC staff training on waste management.

- Preventing waste is the preferred option and sending waste to landfill should be the last resort.

- **Prevention** is the only non-waste option in the framework. It can be achieved through more efficient consumption of products and resources. Fleet optimization and route planning are the examples that use vehicles more efficiency and prevents garage waste due to excessive consumption.

- **Preparing for reuse** is the best option when a product is wasted. Retreading tires in construction are examples of this option.

- **Recycling** is the next best option. Setting clear targets to increase recycling and reduce landfilling are necessary. Recycling plants must be monitored regularly to ensure negative environmental impact from recycling processes are minimized. For example, recycling of used lead acid batteries creates considerable amounts of lead, which can be used in production of new batteries.

- **Recovery** is the fourth option and refers to recovering energy from waste. Energy recovery plants must be monitored regularly to ensure hazardous gases are not emitted to the air during incineration. Example: Tires can be used as fuel for cement kilns or urban heating.

- **Disposal** is the least preferred option and should be avoided, where possible. Landfilling is always preferred over open dumping. Example: disposal of the empty containers of AC refrigerant R134a allows the gas residues to leak into the air.

- Based on the results of environmental analysis in this report, in most cases, if a more favorable waste management option is available at a farther location, **transportation** of waste is recommended. The negative environmental impact of transportation was found negligible as compared to the benefits of the preferred option such as recycling.

- The Waste Framework Directive provides a general framework of waste management and should be used **for guidance only**. For some products, for example, the products which are energy intensive to recycle but safe to landfill, landfilling is preferred over recycling. End of life assessment studies are needed to ascertain the best waste management options for each type of waste in different geographical contexts.

2. Limitations and future studies

The results of this study were generated using different sets of data. For used oil, firsthand data were collected from delegations in Kenya, South Sudan, and DRC. For oil filters and batteries, LCAs were done using relevant data and reasonable assumptions to fit ICRC operating context. For the rest of the garage waste, academic literature and practical benchmarks were used to create recommendations. Therefore, the study is subject to some limitations.

As for used oil, although first-hand data significantly increased the reliability of the study and its recommendations, not all the data were available to be collected, mainly due to the reluctance of the refinery facility (Powerex). Therefore, some assumptions were made, for example, about the washing water in activated clay. Further primary data collection is recommended as the changes in parameters of the refinery processes can impact on the final results.

As for the rest of garage waste, the best of effort was made to use made to use case studies, literature, and benchmarks from less developed or developing countries. However, we acknowledge that these studies might not fully represent ICRC's operating context and therefore the recommendations should be regarded as general guidelines. The authors of this report highly recommend that in future, for more robust results and recommendations, ICRC conducts original environmental analysis using primary data collected directly from the countries where ICRC works, similar to the study conducted for used oil.

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