REINFORCE

UNCERTAINTY IDENTIFICATION AND HIRADC FOR COLLECTION AND REVERSE LOGISTICS

Deliverable 3.1

10/2023

Funded by the European Union

Funded by the European Union Horizon Europe research and innovation programme under Grant Agreement No. 101104204 (REINFORCE). Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or INEA. Neither the European Union nor the granting authority can be held responsible for them.

Funded by the European Union

REINFORCE	
Project Name	Standardised, automated, safe and cost-efficient processing of end-of-life batteries for 2nd and 3rd life reuse and recycling
Funder	European Union
Programme	Horizon Europe
Call	HORIZON-CL5-2022-D2-01-10: Streamlined collection and reversed logistics, fully automated, safe and cost-efficient sorting, dismantling and second use before recycling
Duration	48 months
Start date	01/06/2023
End date	31/05/2027
Budget	4.999.993,75€
Website	https://reinforceproject.eu/

PROJECT PARTNERSHIP

Name	Role	Type	Country
INEGI	Coordinator	RTO	PT
CEA	Beneficiary	RTO	FR
ABEE – Avesta Battery & Energy Engineering	Beneficiary	Enterprise	BE
ITE – Instituto Tecnológico de la Energía	Beneficiary	RTO	ES
TECNALIA	Beneficiary	RTO	ES
NUTAI	Beneficiary	Enterprise	ES
COMAU	Beneficiary	Enterprise	IT
LUT University	Beneficiary	University	FI
THI - Technische Hochschule Ingolstadt	Beneficiary	University	DE
VDL Staalservice BV	Beneficiary	Enterprise	NL
VDL Parts BV	Affiliated Entity	Enterprise	NL
SIRO	Beneficiary	Enterprise	TK
Cobat Servizi	Beneficiary	Enterprise	IT
Everledger	Beneficiary	Enterprise	IE

NAME OF THE DELIVERABLE	
Deliverable Code	D3.1
Due Date of Delivery	30/11/2023
Actual Date of Delivery	30/11/2023
Responsible Organisation	ABEE
Contributing Organisations	3DS, INE, COM, SIRO, VDLP
Name of editor(s)	Juan Jose Jurado Laguna; Jose Maria Silva Corrugedo
Nature	R – Document, Report
Dissemination Level	PU – Public
Version	1.0

QUALITY CONTROL			
Version	**Date of Review**	**Reviewer(s) name**	**Organisation**
Version 1	30/11/2023	Juan Gilabert	ITE
Version 2	30/11/2023	Mario Sánchez Brox	INEGI

Funded by the European Union

INDEX

1. Executive summary

This Deliverable 3.1 report offers a comprehensive assessment of the present risks and uncertainties for the collection and reverse logistics of End of Life (EoL) battery packs. The report covered a general path for reverse logistics, considering the differences between the transportation of batteries either by sea, road, or rail, with an emphasis on road transportation, that is the one to be implemented under the scope of the use cases for the REINFORCE project.

Both risks and uncertainties were determined using assessment tools and strategies, such as Ishikawa diagrams, parting from the experience the members of the REINFORCE project had receiving and storing battery packs and complemented by international standards and guidelines, like AND, ADR and RID regulations for the transportation of dangerous goods.

Hazards were listed and ranked based on their risk probability of happening and the severity of the impact if they were triggered. In contrast, uncertainties were listed considering the currently known processes for transportation, collection, and storage. This led to the creation of a risk matrix, that involved five levels of severity and five levels of event probability.

It was found that 14% of the identified hazards are of the highest level, based on the combined score of both probability and severity. Those hazards can occur regardless of the method of transportation, differences in road, rail, and sea transport do not represent a significant factor in avoiding high probability, hence the control measures to be implemented will be deemed as strict as possible. Thermal runaways and short circuits become the most critical hazards to track since they can also be triggered if other minor risks are left unattended.

Finally, the assessment of the identified hazard has been calculated after the implementation of the control measures defined, allowing us to visualize what the risk status would be. This makes it possible to easily identify the degree of safety control that will be in place in the process. As mentioned in the document, extreme-level risks would disappear and become high-level risks at 15 %.

2. Introduction

Global concern about rising greenhouse gas emissions has led governments to consider more sustainable alternatives in the automotive industry. As a result, measures are being taken to limit their use, and, in turn, strategies are being put in place to promote more sustainable alternatives. Both the predisposition of governments to increase restrictions on the circulation of motor vehicles and the strategic planning of the industrial chain of electric vehicles as an alternative for transportation are marking a transition to a system where the reuse of materials and their recycling are fundamental. All this, in addition to social awareness of the environmental impact, is driving the demand for electric vehicles and the advance of lithium-ion batteries as a safe and reliable option for energy storage.

In the coming years, a substantial increase in the number of batteries in circulation is expected. To face this situation, it is necessary to establish an industrial plan that includes all the necessary measures to manage them most sustainably. For this reason, strategies are being established to offer a second and third life to batteries in other applications. To be able to do this, it is essential to know the whole process involved in this activity. This process's low level of maturity is due to the lack of experience and information, which in turn implies a high degree of uncertainties and risks that must be identified and analysed. That is why we have defined in Figure 1 all the necessary stages in this activity for further detailed analysis. (Jing Lin, 2023)

The objective is to identify the uncertainties, make a risk assessment, and implement control measures of the activity to reduce the grey areas and problems. (Amir Hossein Azadnia, 2021)

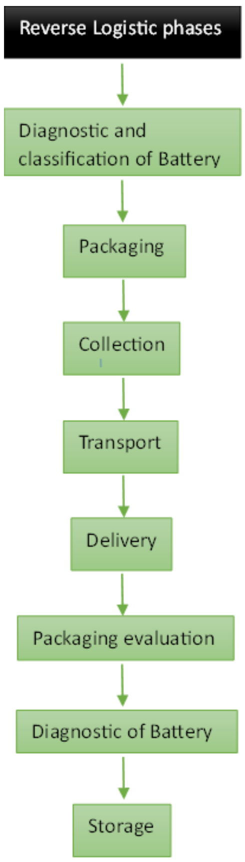


Figure 1. Reverse logistic phases of EoL batteries

3. Methodology

To develop the findings presented in this report, a comprehensive array of analysis and assessment tools were systematically employed. The initial phase involved a unique approach where the analysis deliberately proceeded against the natural flow of the logistics process. Utilizing brainstorming sessions grounded in the firsthand experiences of end users within the REINFORCE project served as a dynamic strategy to unearth potential risks and uncertainties specifically tailored to the collection phase. This innovative starting point allowed for a more nuanced understanding of challenges that might not be immediately apparent in a conventional analysis.

Following this, the application of the Ishikawa diagram, commonly known as a cause-and-effect diagram, proved instrumental in dissecting and visualizing the multifaceted factors influencing the storage of batteries. This systematic method enabled a holistic view of the various elements impacting battery storage, facilitating a more targeted approach to risk mitigation and control measures.

Subsequent to the storage analysis, the transportation of batteries underwent a meticulous examination across three distinct scenarios: road, rail, and inland waterways. An exhaustive evaluation of each mode of transportation was conducted, taking into careful consideration the stringent regulations governing the transportation of dangerous goods. Given that transportation services were outsourced to external entities provided by freight and delivery companies, aligning with and adhering to these regulations was imperative for the safe and compliant movement of batteries throughout the reverse logistics process.

To synthesize the diverse findings and provide a visual representation of the risk landscape, a comprehensive diagram was developed. This diagram effectively illustrates the percentage distribution of risk levels both before and after the implementation of control measures within the reverse logistics process for End-of-Life (EoL) batteries. This visual aid not only encapsulates the complexity of risk factors but also serves as a valuable tool for communicating the effectiveness of the measures introduced in mitigating potential challenges associated with the reverse logistics of EoL batteries.

In summary, diverse analysis and assessment tools, coupled with innovative approaches such as brainstorming and cause-and-effect diagrams, have allowed for a thorough exploration of potential challenges in the collection, storage, and transportation phases of the reverse logistics process for EoL batteries. This multifaceted analysis sets the foundation for informed decision-making and the development of robust risk mitigation strategies within the broader framework of sustainable battery management.

4. Regulatory framework and standards

The work developed for this report is based on the regulations established by international organizations. For rail, road, and sea transport of batteries, the ADR, RID, and IMDG guidelines for the transportation of dangerous goods were considered, respectively.

ADR (Accord européen relatif au transport international des marchandises Dangereuses par Route), also known as the European Agreement concerning the International Carriage of Dangerous Goods by Road, is an international legal framework developed by the United Nations Economic Commission for Europe (UNECE) that governs the transportation of dangerous goods by road. Under this regulation, lithium-ion batteries are divided into two main categories based on their nominal energy: nominal energy (per battery) ≤ 100 Wh, and nominal energy (per battery) > 100 Wh. Subsequently, for each one of the main divisions, batteries will be classified on three different categories based on their presentation; batteries without equipment, batteries packed with equipment, and batteries contained in equipment; as seen in Figure 2.

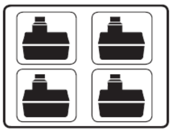
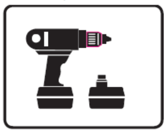
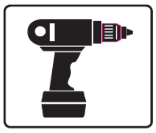
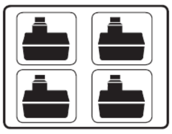
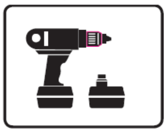
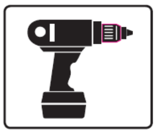
Transportation Mode	Road / Rail (ADR/RID), Sea Freight (IMDG Code)		
Nominal Energy	≤ 100 Wh (per battery)		
Description	**Batteries** (without equipment) 	**Batteries packed with equipment** (at least one battery which is not attached) 	**Batteries contained in equipment** (contained/plugged-in) 
Special Provision / Packing Instruction	ADR/RID SP 188, IMDG Code SP 188		
Nominal Energy	> 100 Wh (per battery)		
Description	**Batteries** (without equipment) 	**Batteries packed with equipment** (at least one battery which is not attached) 	**Batteries contained in equipment** (contained/plugged-in) 
Special Provision / Packing Instruction	P903, LP903	SP 390, P903, LP903	

Figure 2. Batteries classification based on nominal energy and presentation.

Depending on which of the previously mentioned classifications the batteries are allocated, specific criteria will unfold for corresponding packaging and labelling for visual identification. Batteries with nominal energy ≤ 100 Wh have no limit in terms of quantity, and the regulation applied to packing, code SP188, is the same for the 3 presentation classifications. However, for stand-alone batteries (batteries without equipment) there is a weight limit of 30 kg gross (per package). Batteries packed with equipment or contained in it, have no weight limit.

Lithium-ion batteries are considered as dangerous goods, packages containing batteries must visually indicate it by means of a label placed outside the box or container. Such label indicates if the battery (or batteries) is packed without equipment, with equipment or contained in the equipment. Examples of labels associated with the nominal energy are seen in Figure 3.

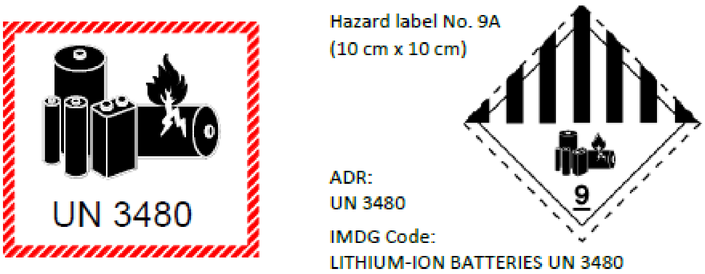


Figure 3. Left, label for stand-alone batteries with a nominal energy ≤ 100 Wh. Right, label for stand-alone batteries with nominal energy > 100 Wh

There are a number of special provisions (SPs), but there are no limited quantities or excepted quantities. The following SPs apply for the following UN numbers for transport by road as show the Table 1.

Table 1: Special provisions of road (Croner-i, 2023)

UN number	Proper shipping name	Special provisions that apply
UN 3090	Lithium metal batteries (including lithium alloy batteries)	188, 230, 310, 376, 377, 387, 636
UN 3091	Lithium metal batteries contained in equipment, or lithium metal batteries packed with equipment (including lithium alloy batteries)	188, 230, 310, 360, 376, 377, 387, 390, 670
UN 3480	Lithium ion batteries (including lithium ion polymer batteries)	188, 230, 310, 348, 376, 377, 387, 636
UN 3481	Lithium ion batteries contained in equipment, or lithium ion batteries packed with equipment (including lithium ion polymer batteries).	188, 230, 310, 348, 360, 376, 377, 387, 390, 670
UN 3536	Lithium batteries installed in cargo transport unit lithium-ion batteries or lithium metal batteries	389

Both RID (Règlement concernant le transport international ferroviaire des marchandises Dangereuses), also known as the Regulations concerning the International Carriage of Dangerous Goods by Rail, and IMDG (International Maritime Dangerous Goods) as the code that provides a standardized framework to ensure the safe transportation of dangerous goods by sea; are aligned with the ADR regulation, whereas classification, packaging, labelling, marking and documentation of goods is similar and can be found on the previously shown figures above.

The AS/NZS ISO 31000:2009 is an international standard that provide guidelines and principles for risk management. It is applicable to any organization, regardless of its size, industry, or sector, and it aims to assist organizations in establishing and integrating effective risk management processes into their overall management systems.

5. Uncertainties identification

The volume of batteries in circulation will increase enormously in the next few years, this is an added difficulty in the reverse logistic process of EoL in batteries. As mentioned above, as this is a new activity, the starting point lacks information and experience in this whole process, which implies an effort and added value in defining and identifying each activity and sub-processes related to the main activities.

This initial context causes a high level of uncertainty compared to other activities with more maturity. However, it is necessary to streamline the whole process to promote its integration into industrial activity.

Identifying uncertainties in activities and procedures is essential for developing the reverse logistics process for EoL batteries. Thanks to this identification, it will be possible to reduce grey areas, and risk and analyze the challenges and problems of the activity so that the safety of the industrial process can be improved.

With all this, we want to achieve a higher level of maturation of the process to streamline the industrial integration properly.

The methodology used to identify uncertainties will be explained below.

Once the phases of the inverse process have been defined, it is necessary to analyze each of the activities to be carried out. These activities are associated with procedures for carrying them out. Depending on the definition and maturity of the activities and their procedures, there will be a greater or lesser degree of uncertainty.

Therefore, the objective is to identify the uncertainties that exist in the activities to define new approaches in the activities and procedures that allow to reduce the level of risk and future problems. (Lukas Marthaler, 2022)

Some general uncertainties have been identified for all activities in the process. Subsequently, three stages of the process have been defined to analyse uncertainties:

5.1. General uncertainties

The first uncertainty is creating an emergency plan due to a critical event with a damaged battery (thermal runaway, swelling, electrolyte loss, cell strike, gas emissions). Currently, there is yet to be a plan on how, when, who, and what to do in a thermal runaway situation. It has to be taken into account that action has to be taken depending on the battery (energy and chemistry).

The second uncertainty concerns creating an action plan due to a non-critical event with a damaged battery (swelling, electrolyte leakage, cell strike, gas emissions). There needs to be a plan on how, when, by whom, and what to do with damaged batteries. It has to be taken into account that action has to be taken depending on the battery (energy and chemistry).

5.2. Preliminary diagnostic processes of the battery in the collection phase.

The third uncertainty displayed in this activity is the identification by the passport of the battery. The information this document will provide should be standardized to diagnose the battery's state. For example, it would be helpful to know the SoC, SoH, SoP, etc. This uncertainty will be addressed in task T2.3 of the REINFORCE project. (Plett, 2015)

The fourth uncertainty that is visualized is the tools and strategies for evaluating the batteries. This uncertainty will be worked on in task 3.2 of this project.

The fifth uncertainty displayed is whether the evaluation will be carried out at the module and cell level and whether modules from different battery packs can be combined to achieve functional battery packs.

The sixth uncertainty is the classification of battery packs according to their diagnosis, in task 2.1 the requirements for second-life applications will be defined, and in task 2.2, the requirements for battery recycling will be defined. A classification of the condition of the batteries will be defined based on the requirements.

The seventh uncertainty is under which criteria you will consider that a cell, module, or battery pack should be recycled and how to perform this activity most efficiently. This uncertainty will be addressed in task 2.2 of this project.

The eighth uncertainty is disassembling batteries, modules, and cells optimally and safely, considering the wide variety of manufacturers in the market.

5.3. Process of detection, monitoring, and prevention in transport.

The ninth uncertainty is that there is no guide on properly packaging and transporting the battery depending on the state defined in the fifth uncertainty classification. Definition of regulations for packaging in function of energy (the current regulation only defines for greater or less than 100 Wh). In the case of damaged batteries, on the one hand, the definition of the container system with capacities for measuring pressure, temperature, gases, fire extinction, etc. On the other hand, define the state in which the damaged battery must be sent, the battery power must be discharged to improve safety.

The tenth uncertainty is based on how to discharge the batteries so that the process is fast, efficient, and safe, and what technologies should be used.

The eleventh uncertainty is about the system for monitoring and detecting fires and dangerous leaks during transport. Definition of regulatory rules for the transport of batteries according to energy.

The twelfth uncertainty is about assessing the condition of the package on delivery. Definition of criteria to assess if the package is damaged and definition of the process to follow if the package is damaged.

5.4. Battery storage process.

The thirteenth uncertainty concerns the criteria for storing batteries depending on their condition. Definition of the process and safety measures for storing damaged and undamaged batteries, characteristics of the areas where they are stored and definition of the procedure to be followed when storing them. (Kwade, 2018;2017)

Finally, a fishbone analysis has been developed to analyse the risks and uncertainties involved in storing EoL batteries, as shown in Figure 4. As can be seen, there are main risks, such as thermal runaway, from which bifurcating conditions can cause this risk, e.g. short circuit. Also, there is machinery where you storage the batteries and the condition related to this, e.g. inadequate equipment or deterioration of this.

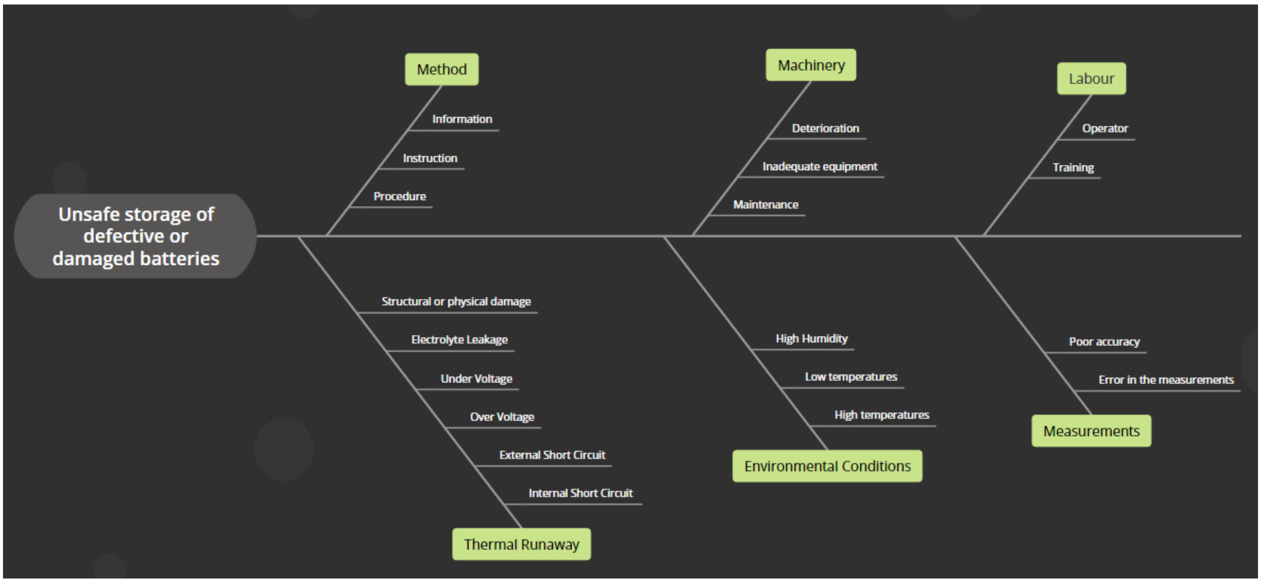


Figure 4: Risk of unsafe storage of EoL batteries

6. HIRADC

6.1. Hazards identification

Risk identification serves to detect potential problems in the collection process and in the reverse logistics stages of the EoL batteries. At this stage it is necessary to identify and analyse each logistic phase to find all existing risks with the ultimate goal of improving safety and optimising the process. (Christoffer Halim, 2020)

The existing risks in activities related to batteries can be due to physical, chemical and electrical risks. It is essential to analyze and reflect on the different phases of the process to identify each of them.

On the one hand, electric batteries can catch fire or explode if they are not handled correctly, which poses a physical and chemical risk due to the gases that can be generated and the explosion itself. On the other hand, there is also an electrical risk due to a short circuit, as there are conductive parts with electrical potential.

These are some examples of the risks of working with batteries. Therefore, it is important to define safety protocols that can mitigate or avoid negative consequences should they occur.

6.2. Risk assessment

A key point in this deliverable is selecting an appropriate methodology for carrying out a proper risk assessment. For this reason, we have analyzed the different alternatives selecting the one that has been considered most efficient and that more relevant information can offer.

With the methodology used, you can make a correct risk assessment to know its impact on the activities individually and globally throughout the process. To do this, general or standardized assessments of the risk level and probability of risk occurring should be defined.

The ranges defined for risk levels range from level 1 to 5, with value one equal to negligible and value five as catastrophic. The following table shows the levels that exist.

Table 2: Severity scale AS/NZA 4360 standard

Level	Description
1	Insignificant
2	Minor
3	Moderate
4	Major
5	Catastrophic

The scales defined for probability levels range from level 1 to 5, with the value 1 equal to rare and the value 5 almost certain. The following table shows the levels that exist.

Table 3: Probability scale AS/NZA 4360 standard

Level	Description
1	Rare
2	Unlikely
3	Possible
4	Likely
5	Almost Certain

Table 4 is a combined matrix of risk frequency, and risk level, that determines how potentially dangerous a risk is. As can be seen, for lower levels of both probability and risk, there is a potentially low dangerous risk, while it increases as the two scales increase. To make this scale more visual, colours have been applied, which helps to interpret the level of danger of the risks defined in the corresponding point. (Radhia Maya R.P, 2020)

Table 4: Risk matrix scale AS/NZA 4360 standard

Risk Frequency	Risk Level Description				
	1	2	3	4	5
1	L	L	M	M	H
2	L	L	M	M	H
3	L	M	H	H	H
4	M	M	H	H	E
5	M	H	H	E	E

6.3. Findings

HIRADC assessment begins with hazard identification throughout the battery collection process and reverse logistics phases of EoL batteries. Each hazard identified shall be analysed in the risk assessment process.

The outcome of the risk assessment shall be used as a trigger to determine the potential risk in the activity and throughout the process. Once the risks and their potential danger have been identified, measures will be monitored to provide solutions that can mitigate or eliminate the risk to the extent possible. Finally, conclusions will be drawn from the results obtained.

6.3.1. Risk analysis

One of the key and most complex points to make is the identification of risks. This identification is carried out in all the activities that complete the reverse logistics process of EoL batteries. For this, it is necessary to analyze in detail each activity, its procedure, and its context, to later reflect on the possible risks that may exist.

An analysis has been carried out of the risks that may exist in the reverse process of collection and storage of batteries. To perform this analysis, the risks when working with batteries have been analyzed, such as electrical, chemical, or physical risks. It has subsequently been analyzed whether these risks may exist in each activity, for example: in handling batteries, packaging with inappropriate materials, etc. This process has been repeated until Table 5. (B. K. Rout, 2017).

Table 5 has evaluated the level of risk that may cause and the probability of it occurring. Using the matrix of both tables as explained in the previous point, Table 4, an evaluation of the potential risk that may exist in the reverse logistic process has been carried out. This table provides an overview of the process safety maturity.

Table 5: Risk list in the collection and storage of the EoL batteries.

No	Risk Description	Risk Level	Probability	Score
1	Thermal Runaway	5	4	E
2	Electrical shock from battery terminals.	5	4	E
3	Swelling	3	4	H
4	Electrolyte loss	3	2	H
5	Storage damaged batteries	3	3	H
6	Gas emissions	4	2	M
7	Transport of damage battery	4	2	M
8	Bad assessment of damage battery	3	2	M
9	Cells struck	3	2	M
10	Damaged battery being shipped	2	3	M
11	Type of packaging material	2	2	L
12	Adverse transport conditions	2	2	L

13	Physical injury from lifting or moving heavy batteries.	2	2	L

The extreme risks of the Table 5 are described below.

On the one hand, the thermal runaway, an event that occurs internally in the battery in which the temperature increases rapidly and uncontrolled due to chemical reactions. This reaction usually causes fire and explosions where molten materials erupt. Its internal reaction cannot be extinguished until the chemical reaction itself ends naturally, so the only option is to mitigate its reaction with retardant materials. This information describes the extreme risk of the event occurring.

On the other hand, the short circuit that in addition to the intricate electrical risk, usually triggers a thermal runaway assuming what was explained in the previous paragraph.

From this table you can obtain relevant information on the level of risk that exists in the process. On the one hand, 14 % of the risk is extreme (E), 21 % of the risk is high (H), 36 % of the risk is medium (M) and 29 % is low. This information is represented in Figure 5.

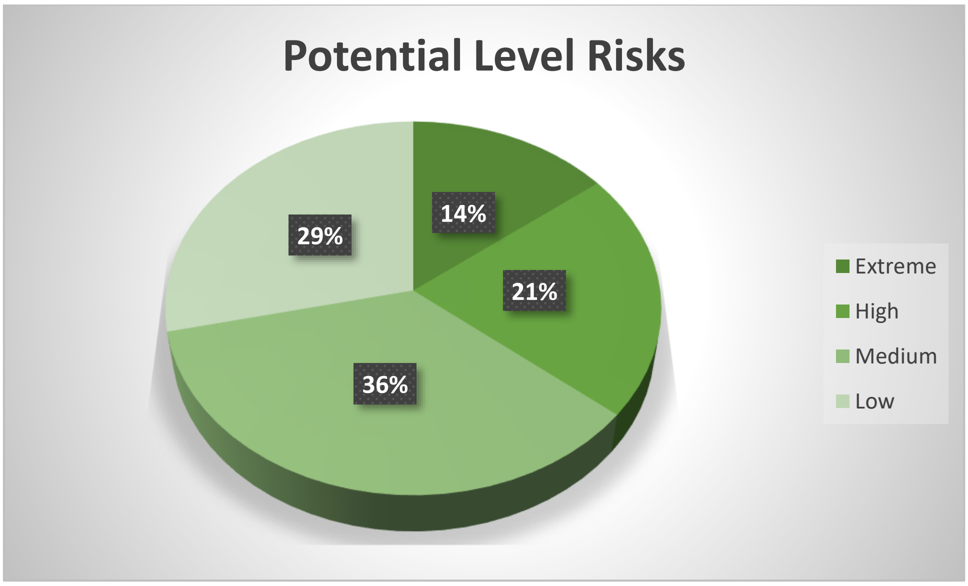


Figure 5: Potential Level Risk

6.3.2. Control measures

This point is one of the key points of the HIRADC document, which will define the most optimal control measures to eliminate or mitigate the risks or hazards identified. To do this, it is necessary to analyse not only the risk, but also the context to choose the most suitable solution.

There are three types of control measures: engineering controls, administrative controls, and personal protective equipment (PPE).

Engineering controls involve modifying the physical environment or equipment to eliminate or reduce danger. (Ts. Khairul Akmal Shamsuddin, 2015)

Administrative controls focus on implementing procedures, policies, and training to minimize exposure to danger.

PPE includes protective equipment such as gloves, glasses, or respirators that are used as a last resort when other control measures are not sufficient.

The control measures are then defined for each risk listed in the previous point:

1. Thermal Runaway
   Control measure:
   - Implement temperature monitoring systems for batteries and fire prevention measures such as fire/resistant storage areas.
   - Ensure proper ventilation and cooling systems in battery storage areas.
   - Regularly inspect and maintain batteries to prevent overheating.
   - Implement automatic extinguishing systems o retardant systems.
   - Train employees on handling procedures.

2. Electrical shock from battery terminals.
   Control measure:
   - Ensure proper insulation and covering of battery terminals.
   - Implement lockout/tagout procedures when working on batteries.
   - Provide appropriate personal protective equipment (PPE), such as insulated gloves.
3. Swelling
   Control measure:
   - Implement a swelling monitoring system for batteries.
   - Providing tools and training on how to respond to swollen cells.
4. Electrolyte loss
   Control measure:
   - Implement an electrolyte loss monitoring system for batteries.
   - Regularly inspect electrolyte loss.
   - Provide spill kits and training on how to respond to electrolyte spills.
5. Storage of damaged batteries
   Control measure:

- Implement a monitoring system for damaged batteries.
- Define procedures for storing batteries.
- Provide appropriate personal protective equipment (PPE), such as insulated gloves.
- Implement proper areas for storage.

6. Gas emissions

   Control measure:
   - Implement a detection system for gas emissions.
   - Provide appropriate personal protective equipment.
   - Ensure proper ventilation system.
7. Transport damaged batteries

   Control measure:
   - Define procedures to transport damaged batteries.
   - Define battery-monitoring packaging systems (gas emission, temperature, etc).
8. Bad assessment of damaged batteries

   Control measure:
   - Define the test and the procedure to assess the damage batteries.
   - Define the classification of the damaged batteries.
9. Cell struck

   Control measure:
   - Implement monitoring with artificial vision to detect struck cells.
10. Damaged battery being shipped

    Control measure:
    - Implement a monitoring system and extinguishing system.
    - Define shipping and security procedures.
11. Type of packaging material

    Control measure:
    - Implement a monitoring system and extinguishing system.
    - Define shipping and security procedures.
12. Adverse transport conditions
    - Define the transport conditions of batteries (temperature).
    - Vibration
    - Low pressure (vacuum)
13. Physical injury from lifting or moving heavy batteries.
    - Provide mechanical aids or lifting equipment for battery handling.
    - Train employees on proper lifting techniques and ergonomics.
    - Implement a buddy system for lifting heavy batteries.

In the following, a table with risk and probability values will be defined, taking into account that the proposed control measures have been implemented. (J.(Eds.), 2018)

Table 6: List of risks in the collection and storage of EoL batteries after implementation of control measures.

No	Risk Description	Risk Level	Probability	Score
1	Thermal Runaway	4	3	H
2	Electrical shock from battery terminals.	4	3	H
3	Swelling	2	3	M
4	Electrolyte loss	2	1	M
5	Storage damaged batteries	2	2	L
6	Gas emissions	3	1	L
7	Transport damage battery	3	1	L
8	Bad assessment of damage battery	2	1	L
9	Cells struck	2	1	L
10	Damaged battery being shipped	1	2	L
11	Type of packaging material	2	1	L
12	Adverse transport conditions	2	1	L
13	Physical injury from lifting or moving heavy batteries.	1	2	L

As can be seen in Table 6 once the defined control measures have been applied, the extreme potential risks have been eliminated and the rest have been significantly reduced.

As can be seen in the Figure 6 the extreme risks have been completely extinguished leaving 15% for the high and medium levels and the remaining 70% for the low level.

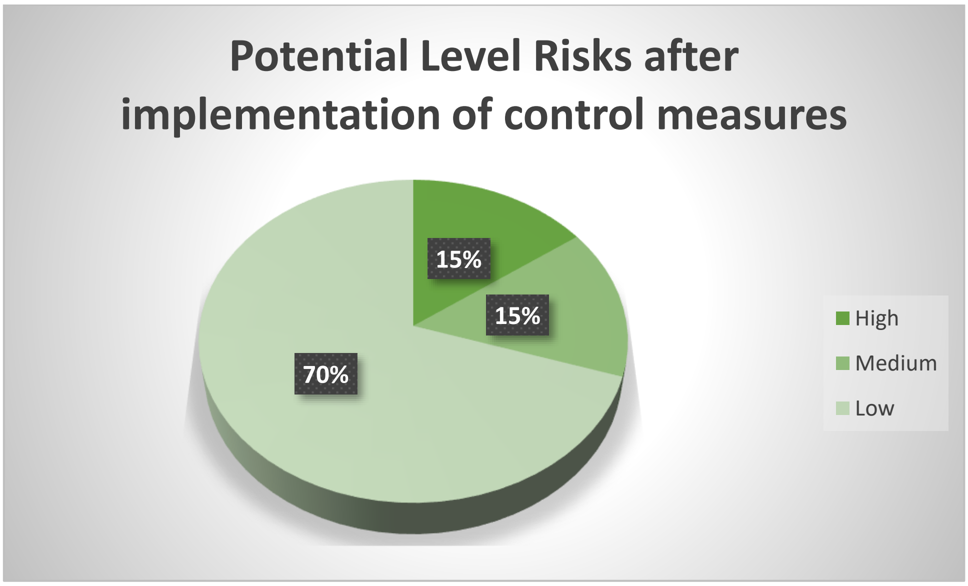


Figure 6: Potential level risk after implementation of control measures

7. Conclusion

In this deliverable the uncertainties in the reverse logistics process for EoL batteries have been identified, this point has been one of the most complex. As this is a new activity, of which there is not much experience and information, the phases and activities of the whole process have been identified in order to analyze each of the uncertainties. Due to this context, there are a number of uncertainties that need to be reduced in order to improve safety and increase the level of maturation of the process.

The result of the HIRADC evaluation shows that 14.29% of all potential hazards found in all activities or processes have an extreme level, 21% have a high level, 36% an average level and 29% a low level. Although this percentage does not represent the majority of possible cases, high-level hazards, once triggered, are not easy to mitigate. Therefore, the effort in control measures for prevention should be as strict as possible, and mutual support measures should be applied. While this percentage does not account for most differences in battery transport methods according to ADR, RID and AND regulations did not result in a significant factor for the likelihood of risk happening.

Control measures and prevention strategies should focus primarily on the top of the matrix, namely the thermal runaway and the short circuit. Both events have an extreme level of potential risk due to their uncontrolled reaction and difficult extinction. Thus, it can be said, that control measures should focus on preventing the event from occurring, and also, that if the event occurs, reduce the risk that this may cause. In addition, it can be observed that some of the risks with a level below the extreme can trigger a thermal runaway, such as storing damaged batteries or swollen batteries, which means that many of these risks are concatenated. This is positive from the point of view of control measures since by defining a control measure for a lower level, you are reducing the risk with a higher level.

Finally, thanks to what was explained in the previous section on the risks linked, and as a conclusion taking into account Figure 6, it is observed that the level of extreme potential risk has been reduced to a high level with a 15%, average 15 % also and the remaining 70 % a low level.

8. References

Amir Hossein Azadnia, G. O. (2021). *Electric Vehicles lithium/ion batteries reverse logistics implementation barriers analysis.* ELSEVIER. Retrieved from https://www.researchgate.net/publication/352882443_Electric_vehicles_lithium-ion_batteries_reverse_logistics_implementation_barriers_analysis_A_TISM-MICMAC_approach

Annie Purwani, W. S. (2022). A Reverse Logistics Framework of Swap Battery for Sustainable Supply Chain : A Preliminary Research. Retrieved from https://www.researchgate.net/publication/366605249_A_Reverse_Logistics_Framework_of_Swap_Battery_for_Sustainable_Supply_Chain_A_Preliminary_Research

B. K. Rout, B. K. (2017). Hazard Identification, Risk Assessment, and Control Measures as an Effective Tool of Occupational Health Assessment of Hazardous Process in an Iron Ore Pelletizing Industry. doi:10.4103/ijoem.IJOEM_19_16

Christoffer Halim, J. R. (2020). Updating Hazard Identification, Risk Assessment, and Determining Control (HIRADC). Retrieved from https://www.neliti.com/publications/511987/updating-hazard-identification-risk-assessment-and-determining-control-hiradc-do#id-section-content

Croner-i. (2023). *Croner-i.* Retrieved from Transport Lithium batteries: https://app.croneri.co.uk/topics/transport-lithium-batteries/indepth

J.(Eds.), D. (2018). *Recycling of lithium/ion batteries: The LithoRec way.* Springer International Publishing. doi:10.1007/978-3-319-70572-9

Jing Lin, X. L. (2023). Design a reverse logistics network for end-of-life power batteries: A case study of Chengdu in China. doi:10.1016/j.scs.2023.104807

Kwade, A. D. (2018;2017).

Lukas Marthaler, P. G. (2022). Key Technical, Policy and Market Devcelopments Influencing the Electric Vehicle Battery Landscape. Retrieved from https://projectcobra.eu/wp-content/uploads/2022/03/COBRA-MI-report-Reverse-Logistics-MARCH-2022.pdf#:~:text=Reverse%20logistics%20in%20the%20context%20of%20EVBs%20start, is%20utilised%2C%20e.g.%2C%20through%20recycling%2C%20repurposing%20or%20remanufacturi

Plett, G. L. (2015). *Battery management systems: Battery modeling. Artech House.*

Radhia Maya R.P, D. H. (2020). Hazard and Risk Analysis by Implementing Hiradc Method in the Laboratory of Medical-Surgical at Faculty of Nursing Universitas Airlangga. doi:10.37506/v11/i1/2020/ijphrd/194043

Ts. Khairul Akmal Shamsuddin, M. N.-A. (2015). Investigation the effective of the Hazard Identification, Risk Assessment and Determining Control (HIRADC) in manufacturing process. Retrieved from https://www.researchgate.net/publication/281224231_Investigation_the_effective_of_the_Hazard_Identification_Risk_Assessment_and_Determining_Control_HIRADC_in_manufacturing_process

Funded by
the European Union

REINFORCE