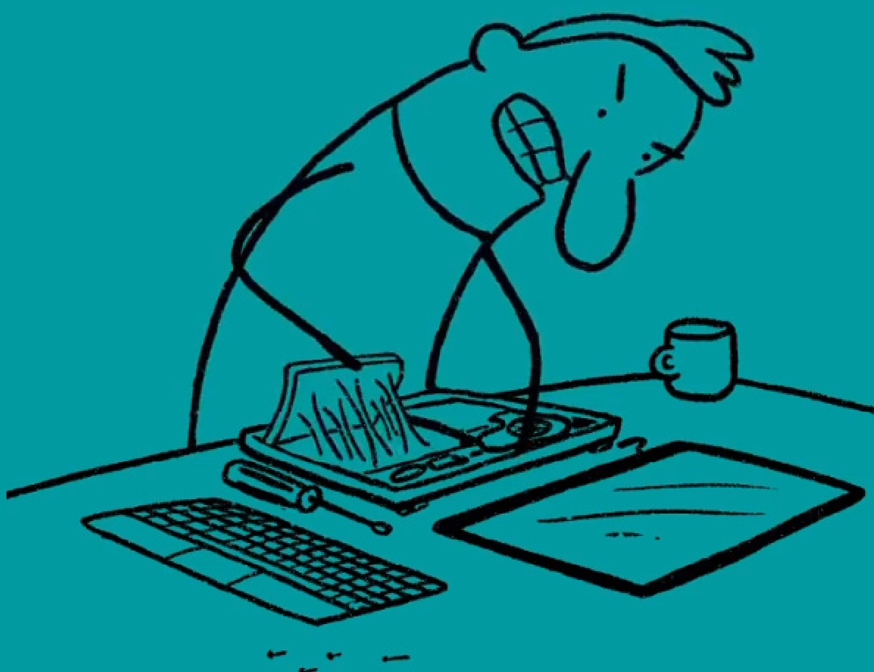
REMOVABLE, REPLACEABLE AND REPAIRABLE BATTERIES

HOW TO IMPROVE THE CIRCULARITY OF RECHARGEABLE BATTERIES IN CONSUMER ELECTRONICS AND LIGHT ELECTRIC VEHICLES



6TH DECEMBER 2021

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ACRONYMS

EOL	End of life
EC	European Commission
EEB	European Environmental Bureau
EU	European Union
GHG	Greenhouse gas
LCA	Lifecycle assessment
LCC	Lifecycle cost
LCO	Lithium cobalt oxide
LEV	Light electric vehicle
LFP	Lithium iron phosphate
LIBs	Lithium-ion batteries
MEErP	Methodology for the Ecodesign of Energy-related Products
PSA	Pressure sensitive adhesive
SOH	State of health

EXECUTIVE SUMMARY

Most portable consumer electronics today are powered by rechargeable lithium-ion batteries (LIBs). In 2015, about 60% of all portable electronics in the European Union (EU) used LIBs. This trend is projected to increase as LIBs have become the battery technology of choice in smart consumer electronics and in light electric vehicles (LEVs). However, the use of adhesives and solder to integrate LIBs means that removing the batteries of most consumer electronics and LEVs requires specialized tools and knowledge. As a result, repair, reuse, and recycling of LIBs and the devices they power has become increasingly difficult, with implications of shorter product lifetimes and less effective recovery of materials.

In December 2020, the European Commission (EC) published a new EU battery legislation proposal. The proposal includes a provision (Article 11) that outlines specific portable battery removability and replaceability requirements that facilitate repair, reuse, and recycling of batteries, consumer electronics and LEVs.

There is a need for more knowledge on these issues, and therefore this report has synthesized evidence on the removability and replaceability of integrated batteries in consumer electronics and LEVs. This report is based on an in-depth literature review of academic journal articles, grey literature, and government reports. In addition, it reports the findings from interviews with three battery refurbishing companies in the EU and a questionnaire with input from 161 repairers of consumer electronics and LEVs from 19 countries across the EU plus the United Kingdom.

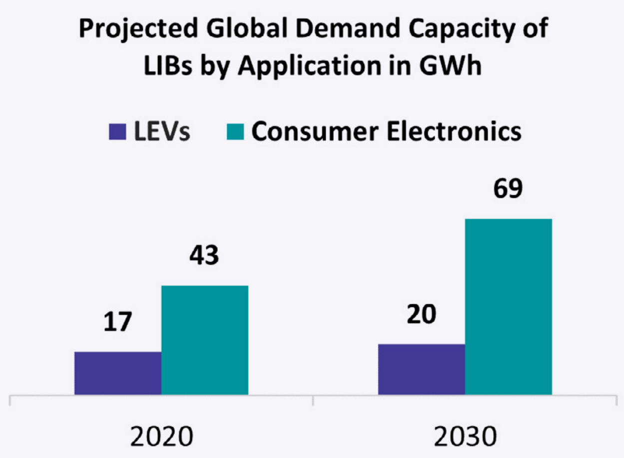
The following provides a summary of the six sections of the report:

1. MARKET OVERVIEW

Global demand capacity for LIB batteries is projected to increase by 60% in consumer electronics and by 15% in LEVS by 2030 (see Figure 1). Laptops and tablets represent over half of the rechargeable LIB market for consumer electronics, closely followed by smartphones. When it comes to end of life (EOL), most the rechargeable LIBs that have reached EOL come from consumer electronics, followed by LEVs. This trend is projected to continue into the next decade.

The trend in both smart consumer electronics and LEVs is to use integrated LIBs. Most consumer electronics use customized pouch-type LIB-cell battery designs fixed with adhesives, requiring specialized tools for removal. The trend in LEVs is towards user-removable battery packs made up of cylindrical (18650) cells. Although the battery packs are usually removable and replaceable, most battery packs are joined with solder or adhesives that are very difficult to open, making it hard to access battery cells for repair, repurposing and recycling.

FIGURE 1 **Global battery demand for LEVs and consumer electronics.**
Adapted from Global Battery Alliance & World Economic Forum, 2019 and Van Tichelen et al., 2019



2. CHALLENGES IN HANDLING NONREMOVABLE BATTERIES

The battery regulation could have significant positive influence in scaling battery repair, replacement, repurposing, and collection. Currently the key challenges that nonremovable battery designs pose to these four areas are:

Battery repair: The casing of battery packs in polymers, and using glue or welding is a major barrier to repairing batteries which is done by refurbishing, replacing cells or components within a battery.[1,2] Software is also increasingly used to prevent battery pack repair. Facilitating battery removability would significantly improve battery repairability and reusability and decrease both the time and cost of disassembly.

Battery replacement: Battery failure leads to shorter product lifetimes because of the difficulty of removing the battery, the risk of damaging other device components while removing the battery[3,4] and the challenges to access spare parts, tools, and information.[5] This study found that battery failure is one of the most common problems for many consumer electronics and often the first component to fail in LEVs.

Battery repurposing: It is estimated that most discarded LIBs have remaining energy storage capacity. While the remaining capacity might not be sufficient to satisfy the needs of the original product, many of these batteries can be repurposed for other applications. Difficult to remove batteries, especially those with proprietary shapes and sizes, pose an enormous challenge to the battery reuse market.

Battery collection: Recyclers and waste operators report that increasingly difficult to remove batteries due to decreasing battery sizes, use of soft pouch cells, and adhesives to fix the batteries have resulted in removing only easier to remove larger batteries. As a result, it is estimated that the LIB collection rates are low and well below national targets. Moreover, difficult to remove batteries have increased the occurrence of fires and safety incidents at waste facilities.

3. BENEFITS OF REGULATING BATTERY REMOVABILITY AND REPLACEABILITY

Using existing lifecycle analysis and lifecycle cost data, the study revealed that removable batteries would increase product lifetimes and decrease their cost and environmental impacts. For example, ensuring that all new phones and tablets sold in the EU in 2030 have easily removable and replaceable batteries has the potential to:

- Reduce the annual greenhouse gas (GHG) emissions of the devices by 674,834 tons CO2e, which corresponds to a reduction of 30% compared to business as usual.
- Decrease the total consumer expenditure by 19.8 billion euros as a result of reducing the unnecessary replacement of devices by 39 million units in 2030.
- Decrease the lifetime societal costs of all new smartphones and tablets sold in 2030 by 725 million euros.
- Reduce losses of critical raw materials like cobalt, rare earth elements, and indium.[6]

4. INDUSTRY CONCERNS

While the use of adhesive and welding to integrate batteries in consumer electronics and LEVs is claimed to bring positive effects on the robustness of the devices (i.e., better ingress protection), it has negative implications for repair and recycling.[5] Industry stakeholders commonly refer to a trade-off between durability and reparability, alluding to the fact that increasing modularity will affect the durability of the device. Moreover, industry stakeholders have also raised safety concerns if batteries were easily removable and replaceable. However, this reports presents evidence to support that modular designs and reversible casing and joining techniques do not compromise ingress protection, weight, or safety requirements, and that the socio-economic and environmental benefits outweigh possible costs.[7–9]

5. CONCLUSIONS

The key conclusions of this study are:

- Nonremovable battery integration techniques result in discarding LIBs that could be repaired or repurposed, and in low collection rates which has increased the number of safety incidents in waste management facilities. Similarly, nonremovable batteries results in replacing or prematurely turning to waste consumer electronics and LEVs that are otherwise functional.
- The market for rechargeable LIBs in consumer electronics is projected to more than double while the global demand for LIBs is projected to grow by 15% by 2030. Therefore, ensuring battery removability and replaceability is imperative to safeguard the environment, economy, and society from the devasting impacts of producing and discarding batteries.
- Improved battery repairability and reusability can be achieved through modular design of battery packs, standardization of cell designs, easy disassembly, and banning software locks preventing battery repair. Improving battery removability and replaceability will reduce the time and cost for battery repair, collection and recycling, and decrease consumer expenditure, GHG emissions, and societal costs.
- Improved battery repairability and reusability achieved

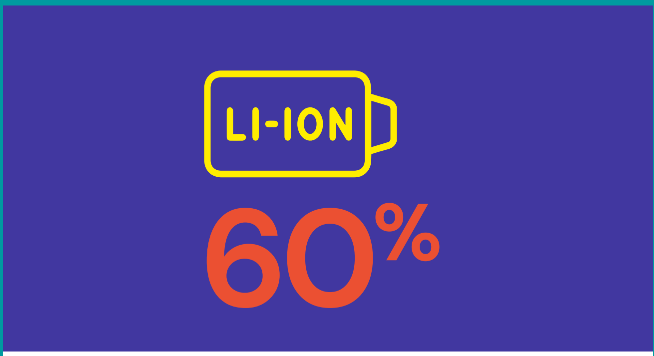
through modular designs and reversible casing and joining techniques do not compromise ingress protection, weight, or safety requirements.

6. RECOMMENDATIONS FOR A BATTERY REMOVABILITY CLAUSE

The new Battery Regulation has the potential to improve circularity of both devices and batteries. For this to happen, article 11 must ensure that:

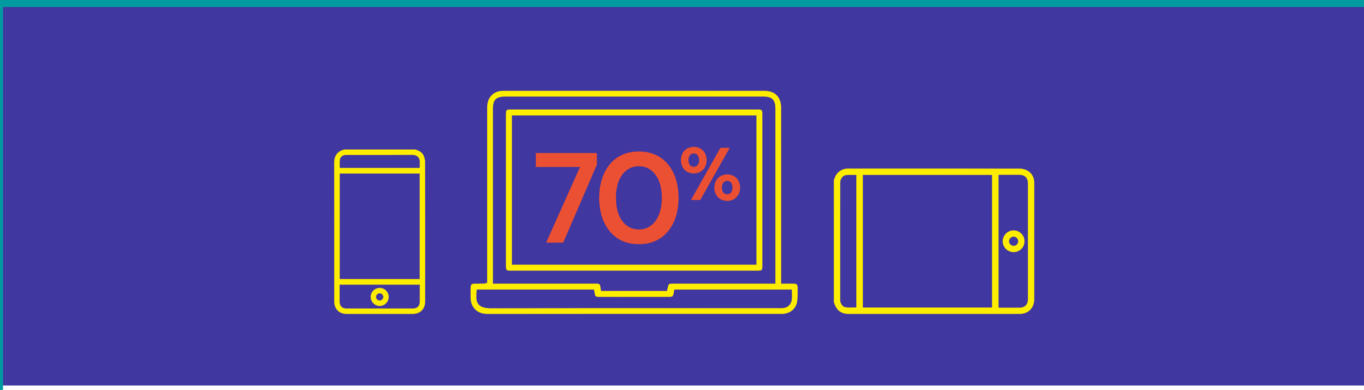
- Integrated batteries avoid nonreversible battery joining techniques and can be readily removable and replaceable by the end-user or by independent operators.
- Battery packs and the cells within the packs are readily disassembled by independent operators with specialized but available tools, and without software being used to prevent repair.
- Manufacturers supply easily understandable information regarding battery replaceability and removability to independent operators and end users.
- Manufacturers supply spare parts and necessary tools from the moment a battery model is supplied until at least seven years after the last unit was placed on the market to independent operators and end users. Any software necessary to repair batteries should also be supplied to independent operators.

OVERVIEW OF BATTERIES IN CONSUMER ELECTRONICS



About 60% of all portable electronics in the EU use rechargeable LIBs and this trend is projected to increase in smart consumer electronics and light electric vehicles (LEVs).

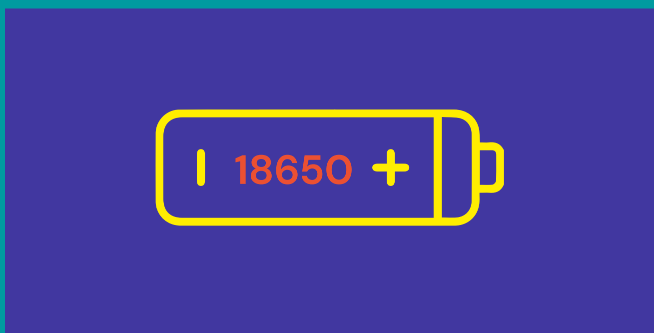
LIBs are a highly relevant product group to the EU since they are the fastest-growing battery technology on the market today and global demand capacity for LIBs is projected to nearly double in consumer electronics and to increase by 15% in LEVs by 2030.



Most of the existing literature on battery removability, repair, and recyclability of consumer electronics focuses on smartphones, laptops, and tablets.

Together, these devices are estimated to make up around 70% of the total EU market for rechargeable LIBs used in consumer electronics.

Global demand capacity for batteries in consumer electronics is expected to increase by 60% in 2030 (from 43 GWh in 2020 to 69 GWh in 2030) .



The most commons cells “used in larger batteries” are the 18650 cells – which stands for 18mm in diameter, 65mm in height, and 0 identifies the cell as cylindrical in shape.

INTRODUCTION

Smartphones, laptops, smartwatches, headphones, e-bicycles, and most consumer electronics Europeans use today are powered by rechargeable lithium-ion batteries (LIBs) which are embedded in the devices. Since 2010 manufacturers have largely replaced standardized LIBs and reversible joining techniques such as pull tabs, clips, and screws for custom-made LIBs and the use of adhesives and solder to join LIBs into electronic devices.[5,9,10] Using adhesives and solders to integrate LIBs means that removing the batteries of most consumer electronics is no longer a simple task, as it requires specialized tools and knowledge.[9,10] As a result repairing, reusing, repurposing, and recycling LIBs and the devices they power has become increasingly difficult and sometimes simply impossible.

Difficulty in removing the battery pack or cell, the risk of damaging other device components while removing the battery, and the challenges to access spare parts, tools, and information results in disposing of LIBs that could be repaired and given a new life on the original device, or given a second life by repurposing them in a different application.[1,3–5,7,11–14] Similarly, these challenges impede battery replacements and can shorten the lives of otherwise working devices. Moreover, nonremovable LIBs result in low battery collection rates and increased safety incidents in the waste management chain.[10,15–17]

Prematurely ending the life of LIBs and of electronic devices has significant environmental, economic, and social implications. The major environmental impacts of LIBs are energy-intensive material and cell production processes, the use of highly toxic fluorinated compounds, and low recycling rates.[12,18] The bulk of the environmental impact of most consumer electronics happens during the material extraction and production phases.[18] Moreover, the future supply of critical battery raw materials such as cobalt and lithium is uncertain, and current supplies are largely found in politically unstable countries such as the Democratic Republic of Congo.[19] In addition, the mining of these raw materials is linked to significant environmental pollution and social risks (i.e., child labor, corruption) due to poor regulatory environments in the countries raw materials are mined.[18,19] Furthermore, battery nonremovability is linked to high consumer costs as users are pushed to prematurely end the lives of their devices and bear the cost of replacement.[5]

A circular economy approach seeks to minimize environmental impacts throughout the lifecycle of products through increasing their lifetimes, slowing material loops, recycling at the end-of-life (EOL), and closing material loops for sustainable supply chains, particularly for critical raw materials. Repair is a key strategy for increasing product lifetime. Considering the environmental impacts caused by LIBs, the forecasted scarcity of critical raw materials, and the economic burden nonremovable batteries place on consumers, it is imperative that the design of LIBs in products is consistent with a circular economy approach. There is a need to ensure that LIBs are not shortening the life of electronic devices or impairing reuse, repair, or recycling. There is also a need to ensure that product designs are not shortening the lives of LIBs. Furthermore, LIBs are a highly relevant product group to the EU since they are the fastest-growing battery technology on the market today and global demand capacity for LIBs is projected to nearly double in consumer electronics and to increase by 15% in light electric vehicles (LEVs) by 2030.[20,21]

As part of its Circular Economy Action Plan, the European Union (EU) is actively addressing the need to mitigate the impacts caused by LIBs and electronic devices by amending or updating existing legislation, including the Ecodesign Directive and the Battery Directive. As part of this process, in December 2020, the European Commission (EC) published a new EU battery legislation proposal (The Battery Regulation). The proposal includes a provision (Article 11) that outlines specific portable battery removability and replaceability requirements to facilitate repair, reuse, and recycling of both batteries and consumer electronics. However, there is limited data available on battery removability and replaceability in consumer electronics. This report aims to fill this gap by providing an overview of the key issues and benefits of regulating battery removability and replaceability in consumer electronics and LEVs.

ABOUT THIS REPORT

The European Environmental Bureau (EEB) and Right to Repair campaign intend to contribute to the design of Article 11 of the upcoming EU Battery Regulation by synthesizing evidence on the removability and replaceability of integrated batteries in consumer electronics and LEVs. This report has analyzed relevant literature and made use of other data collection techniques (see below) to provide more knowledge on these issues.

The report is organized into six sections:

1. Market overview
2. Challenges faced by repairers and recyclers in handling nonremovable batteries
3. Environmental, economic, and social benefits of regulating battery removability and replaceability
4. Industry concerns
5. Conclusions
6. Recommendations for a battery removability clause

Most of the existing literature on battery removability, repair, and recyclability of consumer electronics focuses on smartphones, laptops, and tablets. Together, these devices are estimated to make up around 70% of the total EU market for rechargeable LIBs used in consumer electronics.[3] Therefore, most examples throughout this report will be based on these product groups. In addition to consumer electronics, this study also looks at battery issues LEVs (e-scooters and e-bikes) given its fast growing popularity evidenced by being the second largest application of LIBs reaching EOL.[20]

This report is informed by an in-depth literature review of journal articles, gray literature, and government reports. In addition, it reports the findings from interviews with 3 battery refurbishing companies that operate in the EU, and a questionnaire with inputs from 161 repairers of consumer electronics from 19 countries across the EU plus the United Kingdom. Of the questionnaire respondents, 52% identified as professional repairers, 25% as refurbishers, and 23% as repair café repairers. Moreover, 25% of the participants live in France, 19% in the Netherlands, 18% in the United Kingdom, and 9% in Belgium.

FOCUS TOPIC AREAS

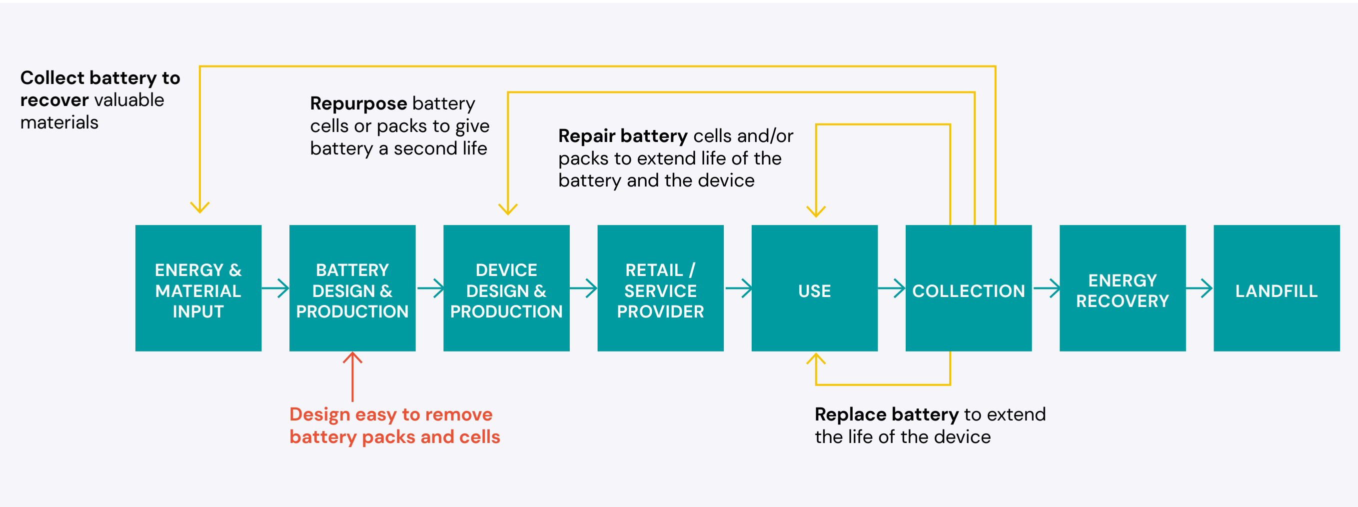
Regulating battery removability brings about many opportunities to improve circularity of both devices and batteries. This report investigates how regulating battery removability impacts battery repair, replacement, repurposing, and collection in consumer electronics and in LEVs (see Figure 2). These areas are described as follows:

1. Battery repair. Refers to bringing a poor performing battery back to full capacity. This can happen either by refurbishing or replacing battery cells or other components of the battery. Refurbishing is possible when poor performance is due to worn out battery cells.[1] Replacement happens when battery cells or other components of the battery have stopped working and refurbishment is not possible. By bringing new life to a battery, repair extends the life of both the battery and the device. Battery repair is often carried out e-bike, e-scooter, tools and industrial robots. Battery repair is often needed when the battery pack is no longer available as a spare part.

2. Battery replacement. Replacing a battery or battery cell is often part of repairing a device and prevents discarding a device that has not reached the end of its useful life.

3. Battery repurposing. Refers to the ability to reuse the remaining energy storage capacity of battery cells and/or pack in an application other than the one the battery was originally designed for. Repurposing a battery extends its life by giving it a second life.

FIGURE 2 Opportunities to increase circularity of batteries and electronic by enforcing battery removability



4. Battery collection. Refers to the ability to recover batteries to recycle valuable battery materials. Collecting batteries allows for the potential to close material loops by reusing valuable materials for other products.

BATTERIES DIRECTIVE

PROPOSED PROVISION

The proposed Article 11 requires that "portable batteries incorporated in appliances shall be readily removable and replaceable by the end-user or by independent operators during the lifetime of the appliance, if the batteries have a shorter lifetime than the appliance, or at the latest at the end of the lifetime of the appliance." [22]

The proposal outlines one exception for devices that require continuity of power supply and a permanent connection between the appliance and the battery for safety, performance, medical or data integrity reasons.

DEFINITIONS

The study uses the definitions of the Evaluation of the Batteries Directive for removability, replaceability, and repurposing:

Removability of the battery is understood to be possible when the battery can be safely taken out of a device (with or without the use of tools). Increased removability is defined as "removable with tools commonly available for waste operators".

Replaceability is defined as a battery (or battery pack) being "removable with tools commonly available to the end-user" and without destruction of the device or battery, thus enabling replacement to support further operation of the device.[10]

Repurposing a battery occurs when a battery pack or battery cell (standalone or within a battery pack) is removed from a device, repaired if needed, and then adapted for use in a different application.[10]

In addition, this report considers battery repair:

Battery repair refers to repair work focused on the battery pack, this can include replacing cells or other key components such as the BMS. The design of the battery pack, the use of glues, putting or welding, as well as software can make battery repair difficult or impossible.[1,2]

BATTERY REPLACEMENT

Many manufacturers change battery designs every 2-3 years and, as a result, consumers find themselves not being able to replace faulty battery packs or having to pay high replacement prices.

When it comes to the time it takes repairers to replace a battery, for the majority of repairers surveyed it takes more than 20 minutes to complete the battery change process for all devices.

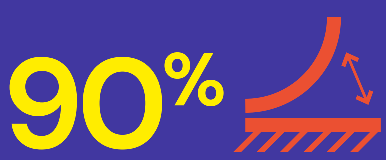
BARRIERS TO BATTERY REPLACEMENT

- AVAILABILITY OF SPARE PARTS
- NON-MODULAR DESIGNS
- PROPRIETARY TOOLS
- GLUES AND ADHESIVES
- SOFTWARE BLOCKS

BENEFITS OF BATTERY REPLACEMENT

- MATERIAL EFFICIENCY
- LONGER LASTING DEVICES
- REDUCED COSTS FOR CONSUMERS

Case and battery joining techniques considered reversible (clips, snap-fits, screws) have been largely replaced by the use of adhesives in the last years for smartphones, laptops, tablets, and headphones.



The market share of smartphones with nonremovable batteries reached 90% coverage in 2017. By 2019, there were no bestselling smartphones that did not use adhesive to join and fasten batteries and housing.

1. Market Overview

KEY POINTS

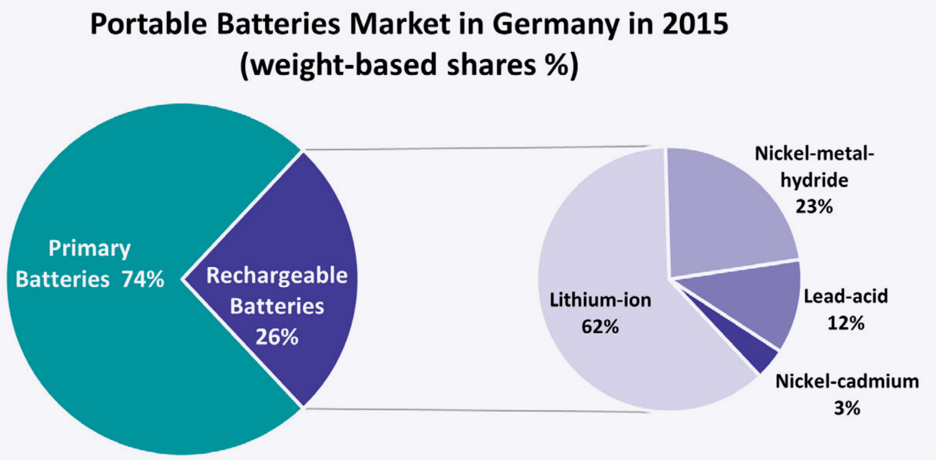
- About 60% of all portable electronics in the EU use rechargeable LIBs and this trend is projected to increase in smart consumer electronics and light electric vehicles (LEVs).
- Global demand capacity for LIB batteries is projected to increase by 60% in consumer electronics and by 15% in LEVS by 2030.
- Laptops and tablets represent over half of the rechargeable LIB market for consumer electronics, closely followed by smartphones.
- The majority of rechargeable LIBs that have reached EOL come from consumer electronics, followed by LEVs. This trend is projected to continue into the next decade.
- The trend in smart consumer electronics is to use customized pouch-type LIB-cell battery designs fixed with adhesives, requiring specialized tools for removal.
- The trend in LEVs is towards battery packs made up of cylindrical (18650) cells and reversible joining and casing techniques for removal of the pack with common tools. Most battery packs are joined with solder or adhesives that are difficult or impossible to remove, making it hard to access battery cells for refurbishing or repair. Repairers are also often faced with software barriers.

1.1. AVAILABLE DATA ON THE RECHARGEABLE BATTERIES MARKET

1.1.1. EU AND GLOBAL BATTERY DEMAND

Available data on applications of portable batteries was only found to have been collected for Germany in 2015 by the Öko-Institut. This data has been used as a proxy for the EU market in a recent EC evaluation of the Battery Directive[3] under the assumption that the data represents the EU population. In their study, the Öko-Institut found that LIBs were the most popular rechargeable batteries for consumer electronics, accounting for 62% of all rechargeable portable batteries in the market (see Figure 3).[3]

FIGURE 3 Portable batteries market in Germany in 2015.
Adapted from Stahl et al., 2018.



Zooming in to the market for rechargeable LIBs, consumer electronics have historically dominated the market. In 2015, rechargeable LIBs for consumer electronics accounted for about half of all rechargeable LIBs in the EU (see Figure 2).[3] Of all LIBs, laptops, and tablets accounted for 55%, mobile phones for 16%, and power tools for 16% of the total market. (see Figure 4)[23].

FIGURE 4 LIBs market in the EU in 2015.
Adapted from Stahl et al., 2018.

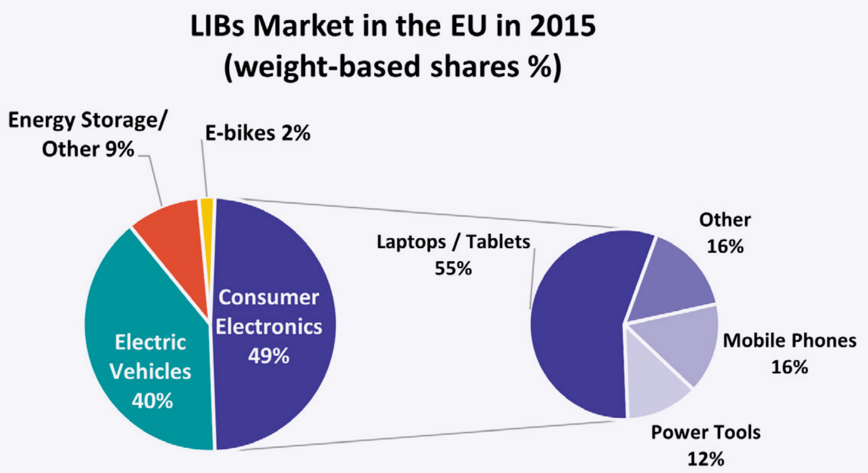
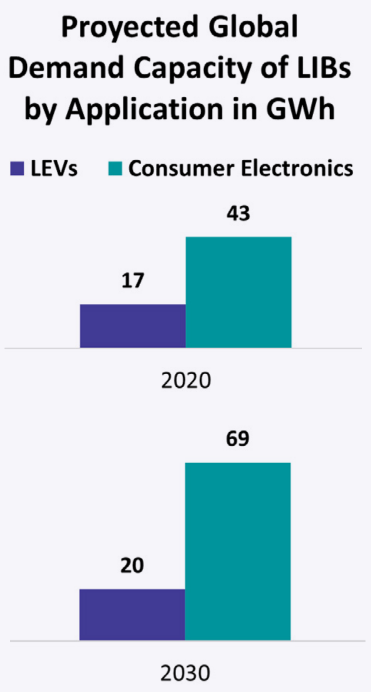


FIGURE 5 **Global battery demand for LEVs and consumer electronics in GWh.**
Adapted from Global Battery Alliance & World Economic Forum, 2019 and Van Tichelen et al., 2019.

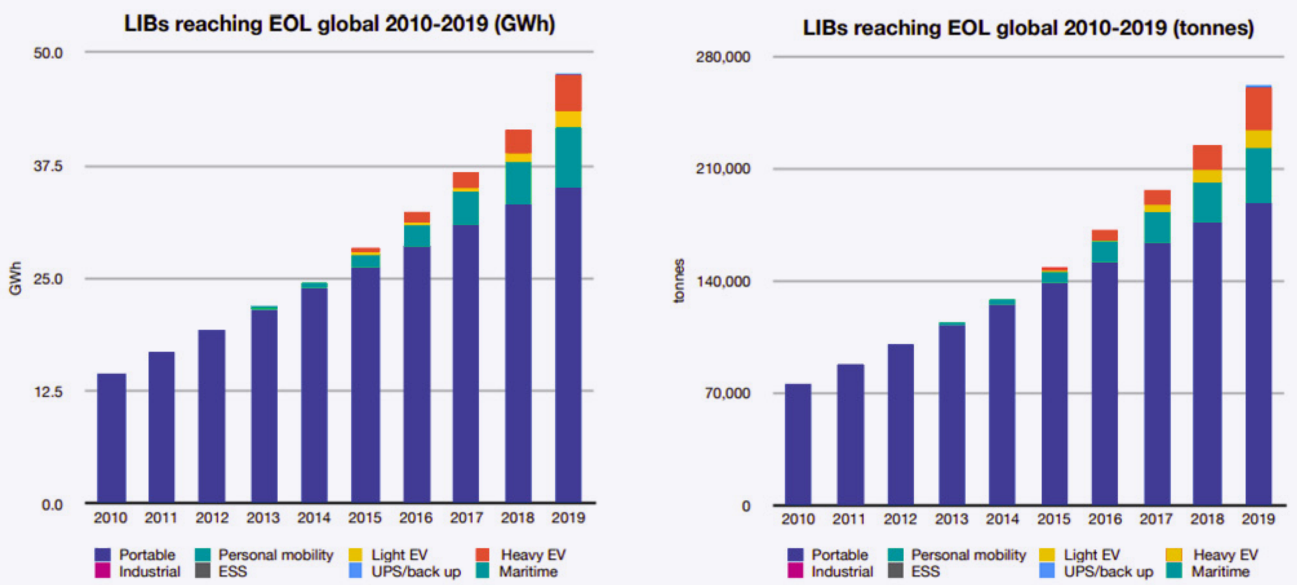


However, starting in 2016, electric mobility surpassed consumer electronics as the largest application for LIBs, and this trend is projected to continue. Nevertheless, even though electric mobility increasingly dominates the market for rechargeable batteries, global demand capacity for batteries in consumer electronics is expected to increase by 60% in 2030 (from 43 GWh in 2020 to 69 GWh in 2030) (see Figure 5).[21] Following a similar upward trend, global demand for LIBs used in LEVs (e-bikes and e-scooters) is projected to increase by about 15% by 2030. The e-bike market is forecasted to be valued at US 92.85 billion in 2027 and the e-scooters market at US 33.5 billion in 2030.[24,25]

1.1.2. LIBS REACHING END OF LIFE

According to data from Circular Energy Storage[20], most rechargeable LIBs that have reached EOL come from consumer electronics, followed by batteries used in LEVs (see Figure 6). The reason behind this trend is that consumer electronics have been using LIBs since their inception in the 1990s. In contrast, other applications (i.e., electric vehicles, energy storage) have not been used in large numbers before 2010 and usually have more than ten years of useful life.[20]

FIGURE 6 **LIBs reaching EOL by application in GWh and tonnes. In these graphs, consumer electronics are labeled as portable electronics and LEVs as personal mobility.**
Source: Circular Energy Storage, 2020.



1.2. TECHNICAL SPECIFICATIONS

1.2.1. BATTERY DESIGNS

Consumer electronics often require high energy batteries that allow for a combined use/stand-by runtime of one to a few days[5]. It is widely assumed that most smartphones, tablets, laptops, and other smart portable devices such as headphones, watches, and speakers use LIB-based batteries.[5,10,20] The chemistry of choice for these devices is lithium cobalt oxide (LCO), given its high voltage, good cycling performance and energy density.[5]

The trend among electronics with tight volume and weight designs is to employ minimalistic and model-specific battery packs made with lithium-ion foils. Battery packs often consist of one or a few battery cells and a battery management board glued to the side of the battery cells. These batteries are packaged as pouch-type cells as they can be easily customized in size and shape.[5] See Table 1 for a summary of the typical battery design and chemistry in consumer electronics.

When it comes to laptops, the newer and slimmer models typically use pouch cells. However, older or lower-end models tend to use battery packs made up of cylindrical cells. The most common cells used are the 18650 cells – which stands for 18mm in diameter, 65mm in height, and 0 identifies the cell as cylindrical in shape.[26]

TABLE 1 **Typical battery design and chemistry by consumer electronic.** *Source: adapted with data from Battery University, 2021.*

Application	Typical Design	Chemistry	Cycle life (ideal)
Mobile phones	Pouch cell	Lithium Cobalt Oxide	500-1000
Tablets	Pouch cell		
Laptops	Pouch cell 18650 cells		
Headphones	Pouch cell		
Smartwatches	Pouch cell		

Batteries used in LEVs have larger batteries than consumer electronics and share characteristics with electric vehicle batteries that are constructed of batteries with multiple cylindrical cells. Cells are combined with a casing for the battery module. These modules are the basis for a battery pack, which additionally needs electronics and a battery monitoring system (BMS). The BMS provides monitoring and management of the charge/discharge processes of the modules to ensure the safety of the battery pack as well as to prevent overcharging and overvoltage of modules.[27] There are three types of BMS: non-intelligent, partly intelligent, and intelligent.[1] The non-intelligent BMS only performs safety functions and from 2020 is no longer used on LEVs. The partly intelligent BMS has a smart charging section that prevents the user from doing things such as connecting a too heavy charger to a light battery. The intelligent BMS is a very complex piece of technology that communicates to the entire bike or scooter and therefore is the most difficult to repair. Bosch and Panasonic are brands known for using intelligent BMS.[1]

Lead-acid batteries have been the battery of choice for e-bikes worldwide as early as 2016, but that has changed as the prices of LIBs have dropped significantly.[24,28] Today, it is estimated 25% of all e-bikes sold in 2020 used LIBs and that proportion is projected to rise to more than 60% in 2023.[28] When it comes to scooters, sealed lead acid batteries have dominated the market due to their low cost and robustness. However, all market projections indicate that LIBs will dominate the market for scooters in the near future.[29] Regarding battery designs, the most typical cells used in e-bikes are the 18650 cells[30] and in e-scooters, the 18650 and 21700 cells[31]. The most common LIB chemistries for e-bikes include lithium nickel manganese Oxide, LCO, and Lithium Iron Phosphate (LFP). For e-scooters, LFP is the LIB chemistry of choice.[30,31]

TABLE 2 **Typical battery design and chemistry by consumer electronic.** *Source: adapted with data from George, 2021 and Foley, 2021.*

Application	Typical Designs	Chemistry	Cycle life (ideal)
e-bikes	18650 cells	Lithium Nickel Manganese Oxide Lithium Cobalt Oxide Lithium Iron Phosphate	1000-2000
e-scooters	18650 cells 21700 cells	Lithium Iron Phosphate	500-700

The overlap in cell and chemistry uses between some consumer electronics, LEVs, and electric vehicles provides an opportunity to leverage synergies to repurpose and recycle batteries.

1.2.2. BATTERY INTEGRATION TECHNIQUES

Research on consumer electronics reveals that case and battery joining techniques considered reversible (clips, snap-fits, screws) have been largely replaced by the use of adhesives in the last years for smartphones, laptops, tablets, and headphones.[5,9] Case and battery joining techniques used in LEVs have experienced a shift towards removable and replaceable batteries.[3] However, our consultations with battery refurbishers revealed that although battery packs are removable they are often impenetrable as they are encased in heavy duty plastic which makes access to battery cells extremely hazardous and sometimes simply impossible.[14]

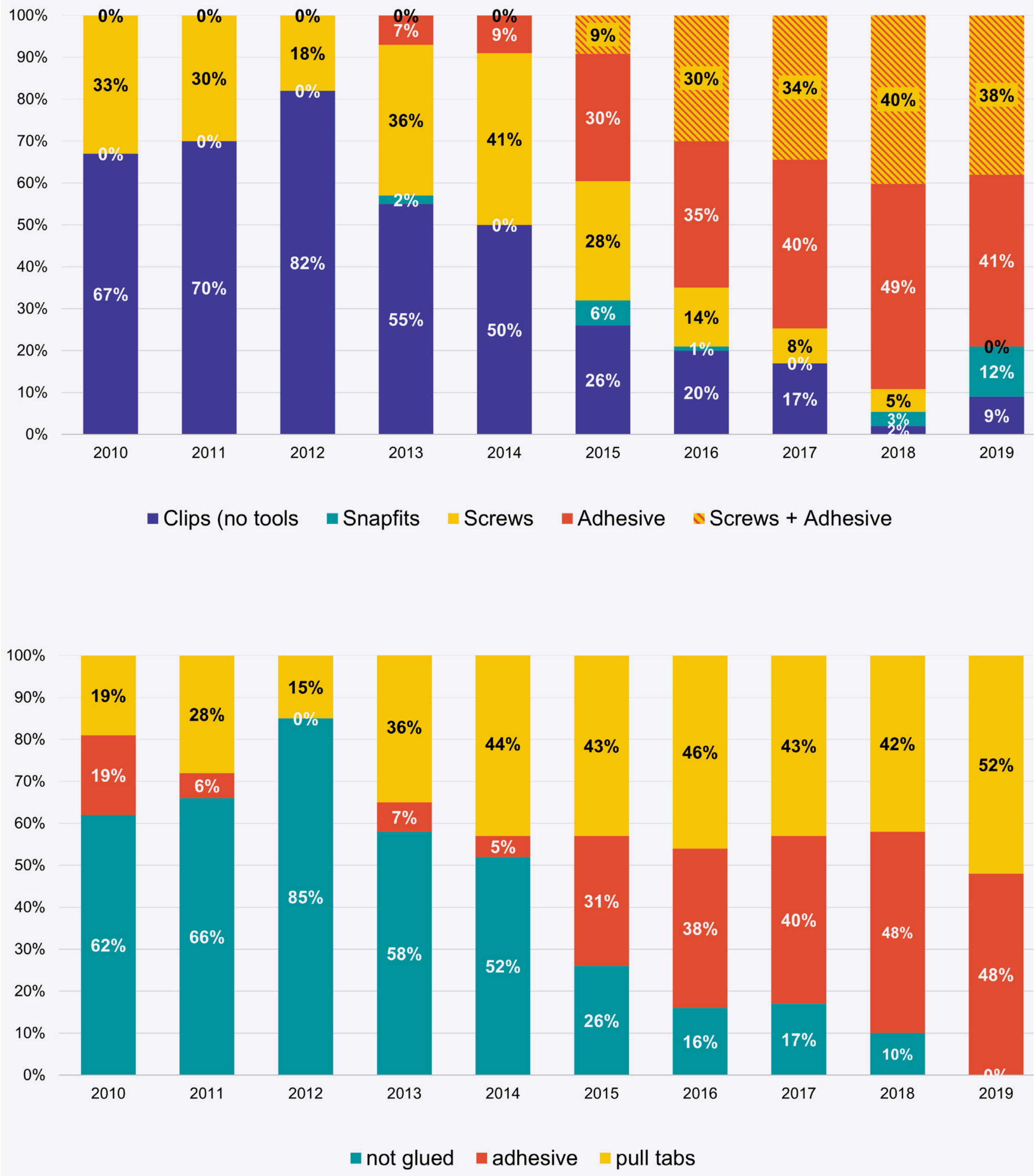
While the use of adhesive in consumer electronics is claimed to bring positive effects on the robustness of the devices (i.e., better ingress protection), it has negative implications for repair and recycling.[5] Industry stakeholders commonly refer to a trade-off between durability and reparability, alluding to the fact that increasing modularity will affect the durability of the device. Moreover, industry stakeholders have also raised safety concerns if batteries were easily removable and replaceable.

However, this reports presents evidence to support that modular designs and reversible casing and joining techniques do not compromise ingress protection, weight, or safety requirements.[9] See section 4 for a detailed discussion on this.

Smartphones

Practically all the bestselling smartphones today feature embedded batteries that cannot be removed without specialized tools.[5,9,10] The market share of smartphones with nonremovable batteries reached 90% coverage in 2017. By 2019, there were no bestselling smartphones that did not use adhesive to join and fasten batteries and housing (see Figure 7).[9] Our survey revealed that 80% of smartphones repaired by respondents have glued in batteries. 90% of our respondents reported that removing and replacing batteries is an increasingly complex intervention.

FIGURE 7 **Evolution of joining and fastening techniques applied to housing (above) and batteries (below) for best-selling smartphones in Europe.**
Source: Berwald et al., 2020 in Cordella et al., 2021.



Laptops and tablets

Similar to the case of smartphones, most bestselling laptops and all tablets today are designed with integrated batteries that can only be removed by unscrewing, peeling away adhesives, and unplugging cables.[4] Two studies that analyzed 21 PC-tablets and 28 laptops found the overwhelming majority had integrated and difficult to remove batteries (20 and 26 devices, respectively).[4] Our survey revealed that 36% of laptops and 100% of tablets repaired by respondents have embedded batteries. The majority of respondents (67% for laptops and 93% for tablets) reported that removing and replacing laptop and tablet batteries is an increasingly complex intervention.

Headphones

Headphones today are overwhelmingly designed with integrated batteries. Our survey revealed that 100% of headphones repaired by respondents have embedded batteries. 83% of respondents reported that removing and replacing headphone batteries is an increasingly complex intervention.

Headphone, and particularly earphone, designs in general can impede battery replaceability. The Apple airpods, with an in-ear design, received much attention for the inability to open the product to replace the battery and receiving 0/10 repairability score from iFixit.[32,33] The latest design, which are over-ear headphones (Airpods Max), include easier accessibility with screws and earns a 6/10 from iFixit, but the overall design still makes it difficult to replace the battery.[34] Batteries that are difficult to remove, especially from wireless headphones and in-ear headphones, means that often the whole headphone is treated as battery when sorted for recycling in professional recycling processes.[35]

Light electric vehicles (LEVs): E-scooters and e-bikes

Market data shows that the trend of e-scooter sharing in cities has led to a shift from integrated to removable and user-replaceable battery packs.[3] Regarding e-bikes, the Confederation of the European Bicycle Industry (CONEBI) has claimed that all e-bikes can have the battery pack replaced, at least by a professional, and that most e-bikes have user-exchangeable battery packs already.[3] Most of the repairers we surveyed

(47%) said that e-scooters and e-bikes they repair do not have embedded battery packs. However, 79% of respondents think removing and replacing battery packs for e-scooter and e-bikes is an increasingly complex intervention.

However, our interviews revealed that user-replaceable battery packs in e-bikes were increasingly difficult to repair because of the battery casing is difficult to open.[14] The most important barrier to repairing e-bike batteries reported in interviews was the use of software by manufacturers to prevent repair. Repairers also reported that many battery pack models, even so they were removable, were no longer available from manufacturers as a spare part, so repairing the battery was the only option for continuing the lifetime of the bike. The inability to open the battery packs and the use of software are therefore key barriers to refurbish, repair or repurpose battery cells or packs.[7,13,14]

2. Challenges faced by repairers and recyclers in handling nonremovable batteries

KEY POINTS

- Design of battery cells and packs with glue or welding can lead to discarding batteries and devices that have not reached the end of their useful life, becoming a major barrier to:
  - Repairing and replacing battery packs or cells in consumer electronics and light electric vehicles (LEVs).
  - Repurposing remaining energy storage capacity of batteries for other applications
  - Safely collecting batteries in consumer electronics and LEVs to recover valuable materials.
- Refurbishers and repairers report multiple barriers to repairing and replacing batteries including lack spare parts and tools, safety considerations, proprietary software, non-interoperability between brands/types of batteries, and an increase in the use of adhesives and solder.

The following section discusses key evidence on the challenges to repair, replace, repurpose and collect batteries, followed by a discussion on how increasing battery removability is key in overcoming existing barriers.

2.1. BATTERY REPAIR

When the battery performance of a device slows down (i.e. the time between each full charge has greatly diminished, the battery is taking a long time to charge, or the maximum performance of the battery is reduced, i.e. the top speed of a vehicle) repair offers the possibility to bring the battery back to full capacity before it fails entirely and needs to be replaced.[1,2] Battery repair can involve refurbishing and/or replacing battery cells or other components of a low-performing battery. Figure 8 gives an overview of a typical repair process for an e-bike which can provide an idea for how battery repair works for other consumer electronics and e-scooters.

FIGURE 8 **Typical process of repairing an e-bike battery.**
Source: Sylvester, n.d.

TYPICAL PROCESS OF REPAIR AN E-BIKE BATTERY

1. Checking the exterior casing and mountings for damage.
2. Opening the housing of the battery pack to access internal components.
3. Identifying any damage or faults with the internal workings.
4. Detaching all pre-existing battery cells in preparation for new or upgraded cells.
5. Cleaning the battery pack.
6. Checking all connectors and wiring.
7. Repairing or re-soldering wiring and connectors where necessary.
8. Replacing any faulty, damaged, or old wiring and connectors.
9. Installing new or upgraded battery cells.
10. Checking the Battery Management System (BMS) functionality.
11. Performing BMS diagnostics.
12. Replacing BMS if necessary.
13. Testing all components.
14. Closing and re-securing casing.
15. Testing new battery components with the existing charger.
16. Testing refurbished battery with the bike's motor to ensure proper function.

Our study revealed three key barriers to repairing batteries: inaccessible design, software blocks, and shortage of spares.

2.1.1. INACCESSIBLE DESIGN

Welded or glued battery casings that are not designed to be open make it impossible to conduct the process of repair which starts by opening the case. A study that interviewed multiple stakeholders about the reuse of LIBs for vehicles found that the design of battery packs with glue or welding was a major barrier to reuse on the cell level.[11] As shown in detail in section 2.2, our consultations with LEVs battery refurbishers and with professional repairers of consumer electronics revealed that impenetrable casings are increasingly common and an important barrier to repairing batteries.[14]

2.1.2. SOFTWARE BLOCKS

Software locks is the biggest barrier for batteries which can be disassembled. Battery refurbishment companies[7,13] indicate that more and more producers are using software locks to prevent refurbishment. Higher-end bikes are reportedly notorious for needing a software reset which cannot be done by independent repairers.[7,13] E-bikes designed and manufactured by Bosch, Yamaha and Specialised were mentioned as examples of brands that use software blocks.[7,13,14] Similarly, some smartphones, such as the iPhone 12, require remote authorization of part replacement using serial number and proprietary configuration apps.[36]

2.1.3. SHORTAGE OF SPARES

Planned obsolescence and supply chain shortages are two explanations for the reduced availability of battery packs or cells. On the one hand, it was reported that many manufacturers change battery pack designs every 2-3 years. Once the design has changed, it becomes extremely challenging to find spares as the manufacturing of the specific battery model stops[7]

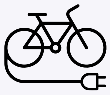
On the other hand, interviewees reported that the LEVs industry is facing a battery cell supply shortage. Some argued that this is because much of the cell production has shifted to the vehicle industry[7] while others say it is because battery suppliers are often not interested in supplying small quantities and a business that solely focuses on refurbishing only needs a few hundred to a few thousand cells per year.[1]

2.2. BATTERY REPLACEMENT

Battery replacements occur when batteries have been damaged or misused.[2] Replacing a battery is often part of repairing a device and prevents discarding a device that has not reached the end of its useful life. Figure 9 describes the typical battery replacement process for an e-bike, which similar to figure 8, can provide an idea of how the process happens with other devices.

FIGURE 9 **Typical process of replacing an e-bike battery.**
Source: Sylvester, n.d.

TYPICAL PROCESS TO REPLACING AN E-BIKE BATTERY

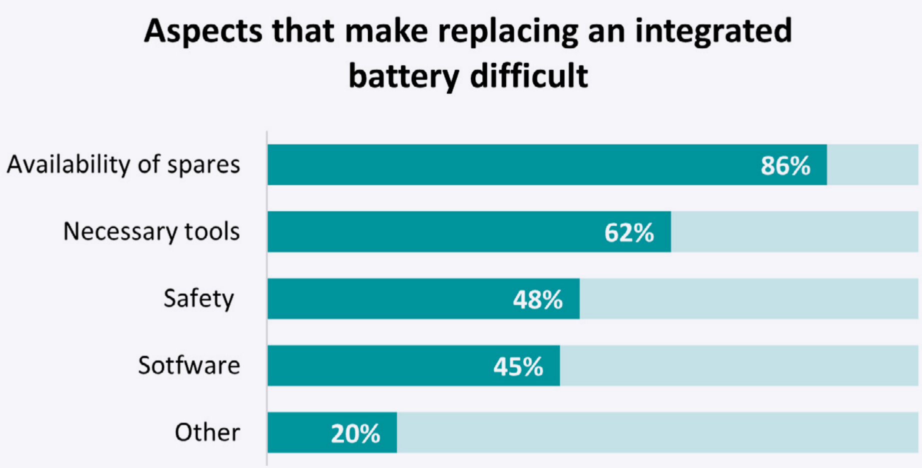


1. The process starts with performing diagnostics to identify the broken or faulty components.
2. The next step in the process is disconnecting and removing the culprit parts.
3. Once the parts have been removed, replacement parts can be installed to return the battery to full working order.

2.2.1. BARRIERS TO BATTERY REPLACEMENT

Similar to the views of professional refurbishers, most of the repairers we surveyed affirmed that lack of available spare parts and tools, safety considerations, and software-related issues are significant barriers that make replacing a battery difficult. One-fifth of the respondents suggested other barriers such as lack of rechargeable battery cells, replaceable battery packs, interoperability between brands/types of batteries, and an increase in the use of adhesives to hold the battery down (Figure 10).

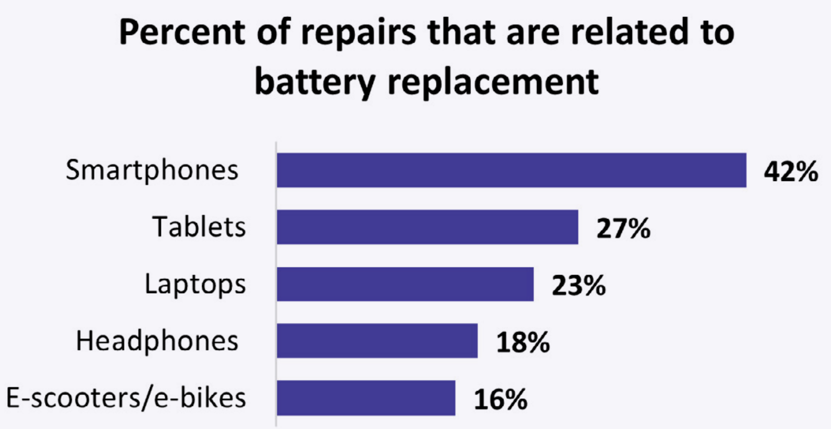
FIGURE 10 **Barriers to replacing a battery.**



For LEVs, interviewers revealed that planned obsolescence of battery packs is a key barrier to battery replacement. Many manufacturers change battery designs every 2-3 years and,[7] as a result, consumers find themselves not being able to replace faulty battery packs or having to pay high replacement prices (i.e. 900 EUR to replace an e-bike battery pack). In response many consumers end up replacing the entire e-bike or e-scooter even when it still is in working condition.[7]

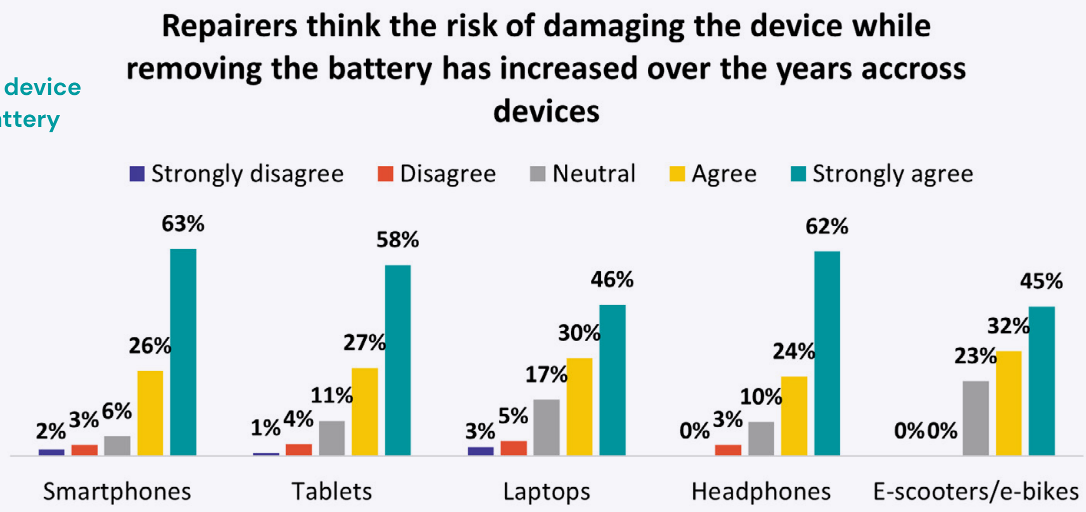
This study found that battery failure is one of the most common problems for many consumer electronics and often the first component to fail in LEVs. The literature suggest that battery-related failures are among the most common failures for smartphones and laptops, amounting to up to half of all repairs (between 17% and 45% for phones and 26% and 45% for laptops).[4,5,9,10] Similarly, our survey revealed that, on average, 42% of all smartphone repairs and 27% of laptop repairs are related to battery replacement. Battery-related repairs were also a common problem for tablets (27%) and to a lesser extent for headphones (18%) and e-scooters/e-bikes (16%) (see Figure 11).

FIGURE 11 **Percent of repairs that are related to battery replacement.**



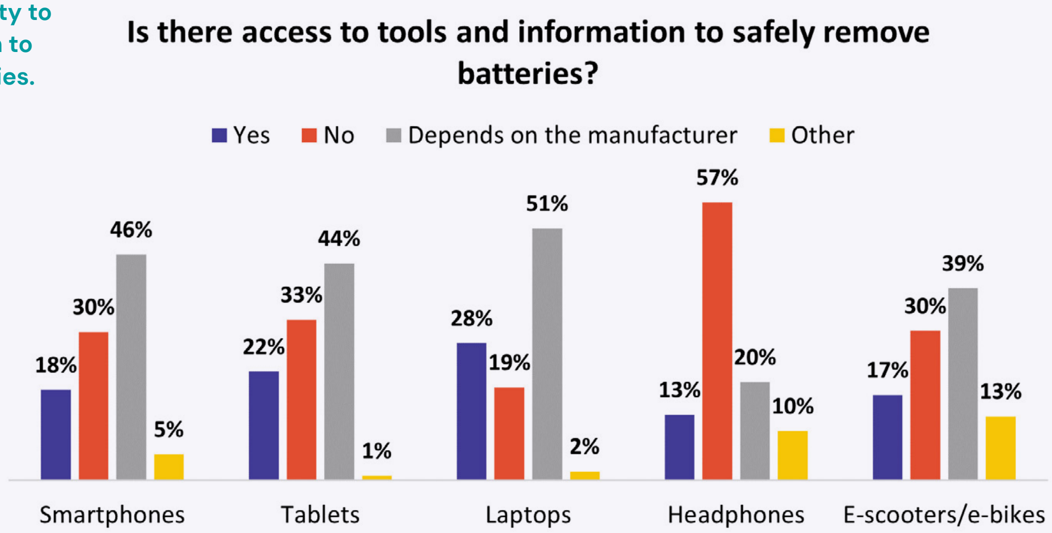
The high percent of repairs that are related to battery replacement is worrisome since our survey revealed that battery life of most headphones is under 1 year, of smartphones under 2 years, and tablets, laptops, and LEVs just over 3 years, and that the experience of most repairers is that the risk of damaging a device while removing a battery has grown over the years due to increasing battery integration (see Figure 12). These three factors combined suggest there a high probability that a significant number of devices are being prematurely discarded due to a battery failure.

FIGURE 12 Level of agreement with increased risks of device damage due to battery integration.



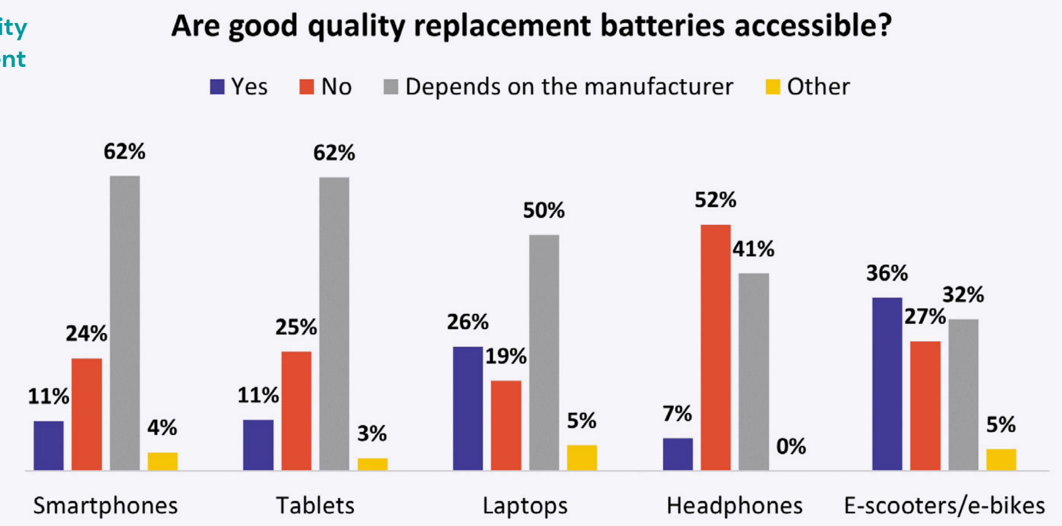
Repairers reported that the accessibility to tools and information for battery replacement depends on the manufacturer when it comes to laptops (51%), tablets (44%), smartphones (46%), LEVs (39%). There was consensus (57%) that information about headphones is not available (see Figure 13). Many of those who reported that information is available specified that this is because of third parties such as iFixit and not because manufacturers publish information.

FIGURE 13 Accessibility to tools and information to safely remove batteries.



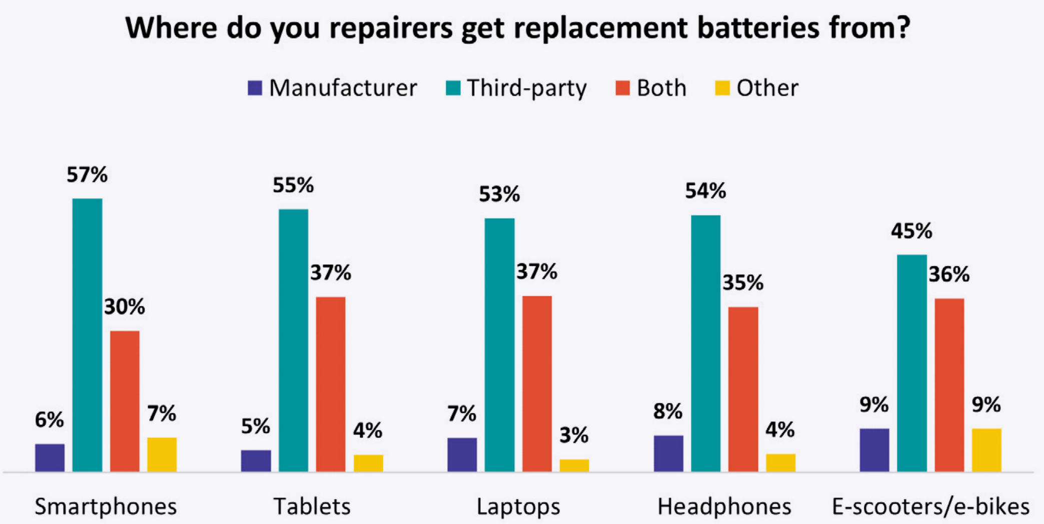
Similarly, most of the respondents reported that access to good quality replacement batteries depends on the manufacturer for smartphones (62%), tablets (62%), laptops (50%). Most repairers (52%) said that good quality replacement batteries for headphones are not available (see Figure 14). The opinion was divided about replacement batteries for LEVs. About a third of the respondents indicated that replacement batteries were accessible (36%), another third that it depended on the manufacturer (32%), and the last third that they were not accessible (27%).

FIGURE 14 **Accessibility to quality replacement spare batteries.**



Over half of the surveyed repairers use third parties to buy replacement batteries for smartphones (57%), tablets (55%), headphones (54%), laptops (53%), and LEVs (45%). About a third of participants use both third parties and manufacturers (see Figure 15). For smartphones and tablets, some repairers report

FIGURE 15 **Spare part procurement.**

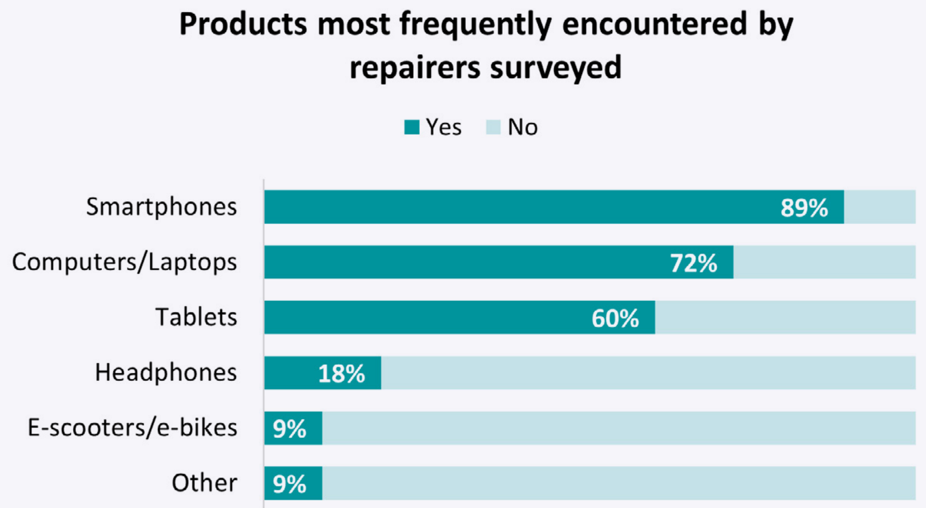


buying batteries from Chinese and/or German distributors or through platforms such as iFixit, Amazon, and Aliexpress.

2.3. CHARACTERISTICS OF FREQUENTLY REPAIRED DEVICES AND REPAIR SERVICES

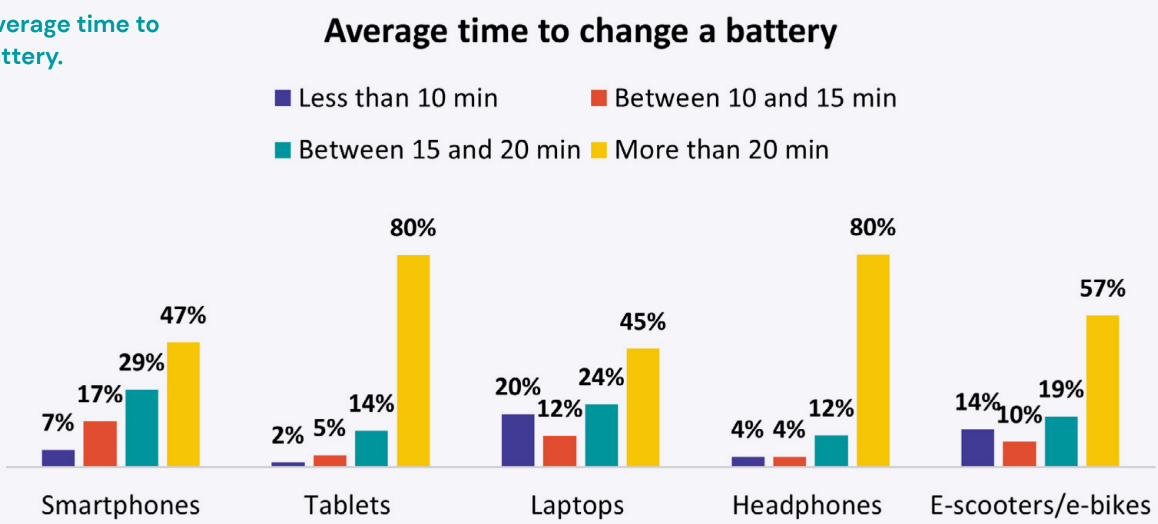
Our survey revealed that repairers mostly see high-value products in their shops, making phones, laptops, and tablets priority items to them in terms of ensuring easy and affordable repairability (see Figure 16). Products that are repaired but not as frequently (other category) include gaming consoles and sound systems, which are also high-value electronics.

FIGURE 16 Products most frequently encountered by repairers surveyed.



When it comes to the time it takes repairers to replace a battery, for the majority of repairers surveyed it takes more than 20 minutes to complete the battery change process for all devices (see Figure 17). The vast majority of respondents (between 75% and 90%) think the time needed to change a battery has

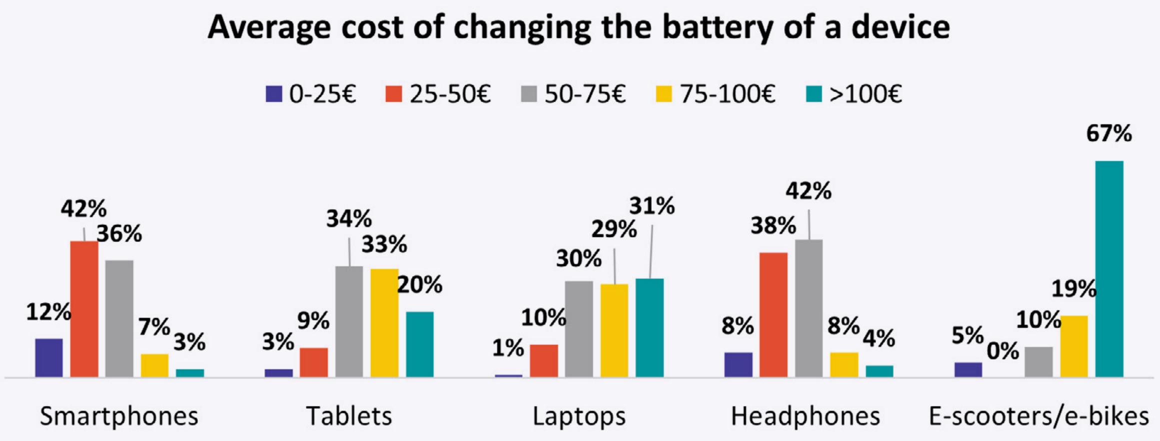
FIGURE 17 Average time to change a battery.



increased for all devices over the past ten years. Supplementary data from iFixit on smartphone repairability shows that battery disassembly steps range from 2 to 46 depending on the model, and that depending on the skills of the repairer, battery replacements can be performed in 30 to 120 minutes.[9]

Regarding the cost of repair for smartphones and headphones, most respondents indicated that it costs between 25 and 75 euros to replace a battery. The price range increases to between 50 and 100 euros for tablets and between 50 to over 100 euros for laptops. Most respondents agreed that replacing the battery of an e-scooter or e-bike costs more than 100 euros (see Figure 18). Moreover, most repairers said the customers are not often dissuaded by the cost of replacing a battery except for tablets. On average, repairers said cost discourages 37% of tablet holders, 25% of smartphones users, 23% of laptop owners, 15% of headphone carriers, and 4% of LEV owners from repairing their device.

FIGURE 18 Average cost of changing the battery of a device.



2.4. BATTERY REPURPOSING

Another issue caused by difficult to remove batteries is that it hinders the ability to reuse the remaining energy storage capacity to give batteries a second life[12]

It is estimated that most portable rechargeable batteries are discarded once their state of health (SOH) has dropped anywhere between 80% to 60%, which is the typically expected life cycle of a battery for most consumer electronics.[37] For instance, testing data from over 600 used LIBs of smartphones and laptops sourced in India between 2011 and 2016 revealed that the average SOH across all the cells tested was 67% (see Table 3).[38] This remaining energy storage capacity might not be sufficient to satisfy the needs of the product the battery is intended to power; however, the battery can often be repurposed for other applications such as solar lights, toys, and energy storage.[12] This is already happening at a small scale with consumer electronics in India, where German-Indian start-up company NUMAN uses LIBs cells from discarded consumer electronics to create mobile power banks. These power banks can power small electronics such as smartphones, lamps, or fans. For example, they used a five-year-old laptop to create a light source for grocery merchants in rural India.[37]

TABLE 3 **Capacity left after smartphone and tablet first life.** *Source: Adapted from Chatterjee, 2019.*

Application	Sample size	Capacity left after its "first life"/ Disposal
Smartphone	303	~ 59 % 0.89 Ah
Laptop	286	~ 70 % 1.63 Ah

According to NUMAN, dismantling used cells at scale at a low cost is a current challenge given varying cell enclosures. Moreover, they report that pouch cells are particularly difficult to reuse given their complex proprietary designs and the fact that they are not built to be repurposed in secondary applications. In contrast, cylindrical cells (i.e., 18650) are significantly easier to reuse because they are standardized.[37]

2.5. BATTERY COLLECTION

Nonremovable, or challenging to remove batteries, decrease the rate of battery collection and increase the risk of safety incidents at waste facilities.

2.5.1. LOW BATTERY COLLECTION RATES

Increasingly difficult to remove batteries are a key explanation for low battery collection rates at EOL. Time and the tools needed to remove integrated batteries affect the ability of consumers to remove batteries before disposal as well as the operational costs for waste sorting at recycling facilities. Currently, it is estimated that around 80% of batteries at waste facilities are removed manually.[15] One of the key reasons for manual removal is the variety of sizes and shapes and the difficulty in identifying the chemistry inside the battery because of lack of proper signage and standard design, making it difficult to automate the sorting process.[39] Recyclers report that battery removal has become increasingly complicated as batteries sizes are decreasing, there is a trend towards soft pouch cells, gluing batteries into the device.[5,15] As a result, waste operators mostly remove the "low hanging fruits" which are usually the larger batteries that are easy to remove (and more promising in terms of recycling content) or batteries found in homogenous waste streams where sorting is not needed.

A study of customer acceptance of toothbrushes with integrated batteries in Germany found that battery removal was complex and affected sorting, collection, and recycling.[40] The researchers related that: *"[the toothbrush] has to be disposed of by removing the battery, which proved to be difficult since the bottom did not open easily as tested by one of the research group members, further proving that this toothbrush was not designed to being able to exchange batteries once the original battery is empty"*.[40] The survey also found that participants could not differentiate between manual, battery, or accumulator toothbrushes when buying a toothbrush based on their appearance alone. When participants were informed that battery-operated toothbrushes lasted for three months and that the battery had to be removed at disposal, 90% indicated that they would not buy them. Lastly, the study revealed that the recycling process explained on the backside of the packaging was misunderstood by 35% of those surveyed, suggesting that a significant proportion of people would dispose of the battery into the normal household waste.[40]

As a result of the challenges involved with LIB collection, it is estimated that the LIB collection rates are low and well below national targets. A study funded by the Swedish Environmental Protection Agency[41] estimated that, assuming people keep their batteries for an average of six years, the collection rate of LIBs in Sweden in 2017 was 11% of the total LIBs available for collection that year. To place things into context, the study compares collection rates of LIBs against collection rates for other battery types. The results show that the collection rate of LIBs is significantly lower than that of any other battery type (see Figure 19). This is also the case for all countries in the EU (see figure 20). [42]

FIGURE 19 LIB collection rates in Sweden 2012-2017 (left) and Portable batteries collection in Sweden in 2017 (right).
Source: Melin et al., 2018 based on data from the Swedish EPAe.

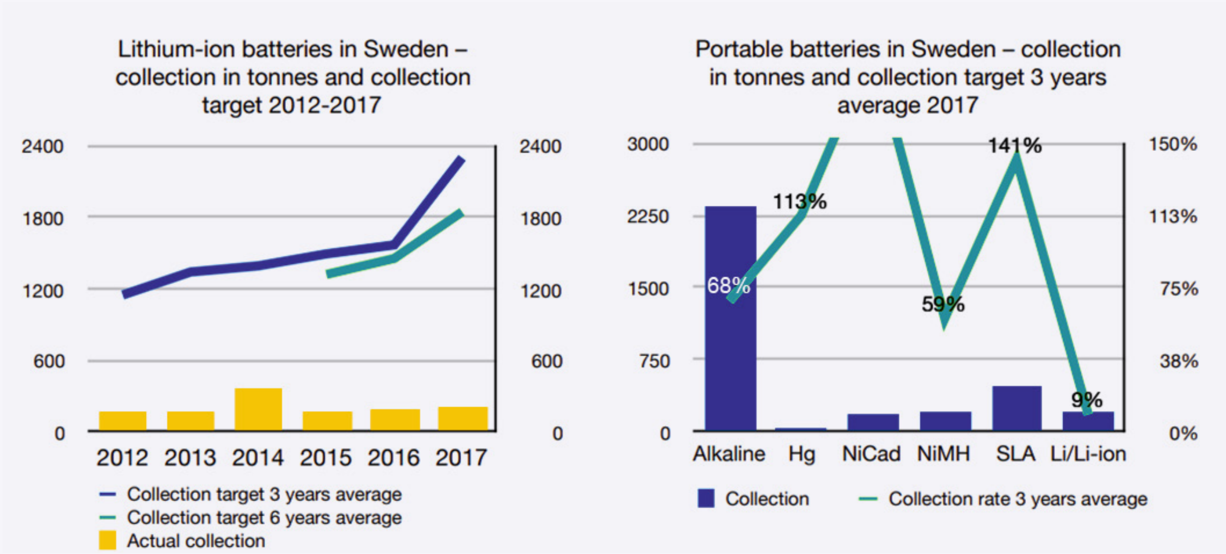
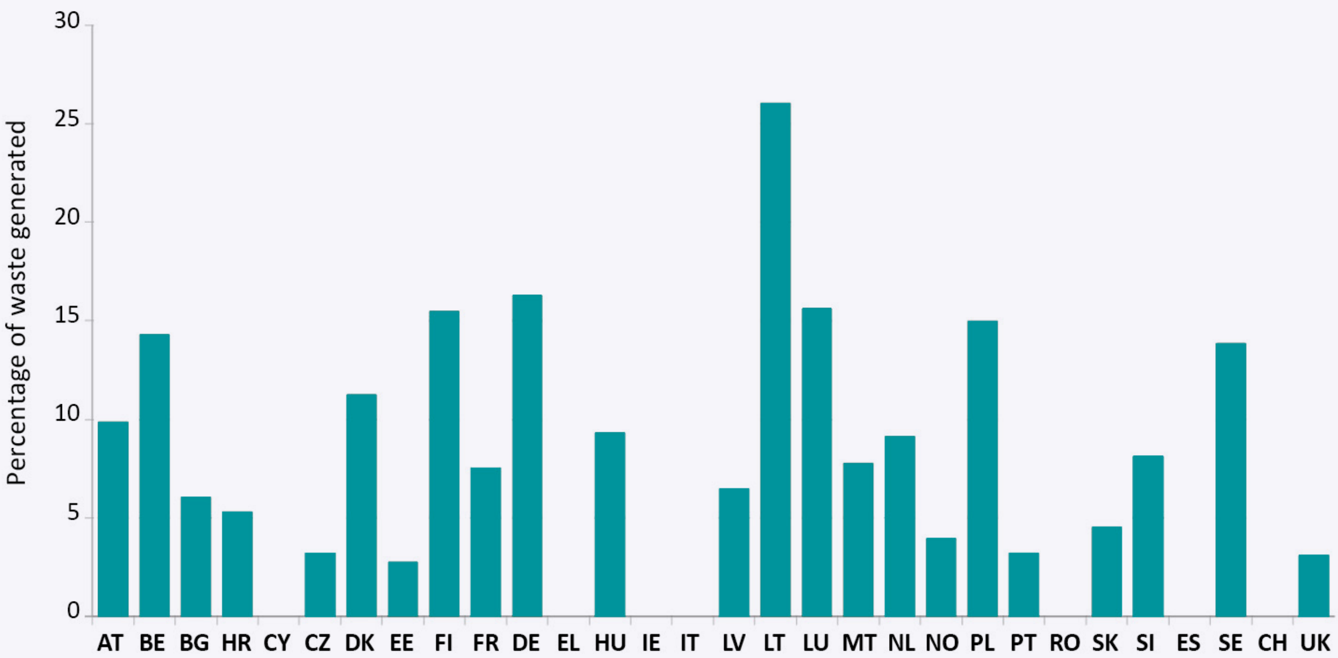


FIGURE 20 Percentage of collected batteries from waste generated in 2015 for rechargeable LIBs.
Source: Urban Mine Platform, n.d.[43]



2.5.2. SAFETY RISKS

Another consequence of the increased difficulty of removing batteries is that the number of fires in the WEEE management chain is growing.[5,10,15] The most affected streams are mixed WEEE and small household appliances, and all studies have attributed the responsibility for the majority of those fires to damaged batteries.[5,15,16] In WEEE management, minor accidents (hot stops, sparks) can happen daily. More significant accidents (explosions, fires) are reported to occur on average once or twice a year.[5] Small and large accidents can occur in any step of the chain, including collection points and facilities, transport vehicles, recycling facilities, and landfills.[16] In some instances, it has been reported that appliances that contain both easily removable and integrated batteries do not indicate having more than one battery anywhere in the product. This lack of information misleads recyclers into thinking there is only one (easily removable) battery and sending WEEE to mechanical treatment without removing all batteries, which increases the risks of safety incidents.[10]

The scale of the fire Incidents in the EU was assessed in a joint report of the WEEE forum and EURIC[16]. The report surveyed over 100 companies from 20 countries in the EU and found that one third of the recyclers surveyed reported very serious fire incidents in connection with defective LIBs. These incidents caused fires that last hours and were only controlled by the intervention of fire departments.[16]

Austrian data also revealed that battery-caused fires and explosions have increased. Between 2007 and 2017 there were, on average, 28 incidents reported each year. Between 2018 and 2019, the average jumped to 82 incidents per year. Batteries are responsible for 50% to 95% of these accidents.[17] In the UK, LIBs have similarly been attributed responsibility for about 48% of all waste fires each year.[44]

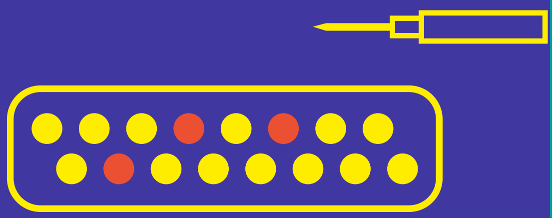
Moreover, the steady increase of battery-related incidents costs millions to companies.[15] An EU-wide survey revealed that the average cost of severe incidents in 2018 alone was estimated at EUR 190,000. Waste fires in the UK are costing around EU 183 million to waste operators, fire departments, and the environment.[44] The average cost of the damages caused by severe incidents of the past four years was estimated at EUR 1.3 million.[15] As a result of the increase in incidents, companies are facing ever-higher insurance premiums, coverage exclusions and are unable to obtain insurance in the worst cases.[15]

2.6. LOWERING BARRIERS TO BATTERY REFURBISHMENT, REPAIR, REPURPOSING AND COLLECTION

Facilitating battery removability would significantly improve battery repairability and reusability. Improved removability can be achieved through modular design of battery packs, standardization of cell designs (to allow easier exchange), and easy disassembly (i.e., using nuts and bolts to assemble the pack instead of welding or glue or holding cells in place with means other than potting or thermo-setting compounds).[45]

Easier battery removal can also decrease the time both repairers and recyclers must spend disassembling batteries from products. The time-intensity and labor costs involved in manual disassembly can increase the overall cost of repair, refurbishing, and recycling activities and become a substantive barrier to upscaling these activities.[46] Beyond economic benefits, and as shown in detailed in the following section, improving battery removability brings significant environmental and social benefits.

BATTERY REPAIR



Refers to bringing a poor performing battery back to full capacity. This can happen either by refurbishing or replacing battery cells or other components of the battery. Refurbishing is possible when poor performance is due to worn out battery cells.

THREE KEY BARRIERS TO REPAIRING BATTERIES

INACCESSIBLE DESIGN

SOFTWARE BLOCKS

SHORTAGE OF SPARES

BENEFITS OF BATTERY REPAIR

MATERIAL EFFICIENCY

LONGER LASTING DEVICES

MORE AFFORDABLE FOR CONSUMERS

LOCAL JOBS

Higher-end bikes are reportedly notorious for needing a software reset which cannot be done by independent repairers.

3. Environmental, economic, and social benefits of regulating battery removability and replaceability

KEY POINTS

Removable batteries will increase product lifetimes while decreasing their cost and environmental impacts. For example, ensuring that all new phones and tablets sold in the EU in 2030 have easily removable and replaceable batteries has the potential to:

- Reduce the annual greenhouse gas (GHG) emissions of the devices by 674,834 tons CO_2e, which corresponds to a reduction of 30% compared to business as usual.
- Decrease the total consumer expenditure by 19.8 billion euros as a result of reducing of the unnecessary replacement of devices by 39 million units in 2030.
- Decrease the lifetime societal costs of all new smartphones and tablets sold in 2030 by 725 million euros.
- Reduce losses of critical raw materials like cobalt, rare earth elements, and indium.

The following section presents available lifecycle assessment (LCA) and lifecycle cost (LCC) data to illustrate the environmental, social, and economic savings from regulating battery removability and replaceability on consumer electronics. The data presented below was adapted from the Ecodesign preparatory study on smartphones and tablets[5], which uses the Methodology for the Ecodesign of Energy-related Products (MEErP). As mentioned in Part 1 above, tablets and smartphones represent over half of the total market share of rechargeable LIBs for consumer products; therefore the findings presented in this section are highly relevant to understanding the social, environmental, and economic gains from regulating battery removability and replaceability.

3.1. SCENARIO

The calculations presented in this section are based on data from select design options presented in the Ecodesign preparatory study. These design options are:

- **Use of reversible battery joining techniques, which means:** Batteries are mounted into the housing with double sided pressure sensitive adhesive (PSA) tapes with stretch-release-properties; PSA systems with adhesion properties are sensitive to contact with ethanol; and battery wrapping technology uses a pull tab attached to the battery wrap.
- **Battery removability/replacement without the use of tools:** batteries can be accessed, removed, and replaced without using any types of tools, thermal energy, or solvents.
- **Provision of repair and maintenance information:** repair information is comprehensive and available to various target groups of repairers.
- **Availability of spare parts to repairers:** provision of priority parts (i.e. battery) and information on repair costs.

The results presented below assume that the legislation is coming into force from 2023 and that 100% of the stock will meet design requirements by 2030.

3.2. IMPACTS ON PRODUCT LIFETIME

Improving battery removability will increase the lifetime of phones and tablets. Based on a lifetime model that considers different reasons and times for products reaching their end of life, improving battery removability on a phone or tablet can extend the life of the device by almost half a year (see Table 4).

TABLE 4 Battery removability impacts on product lifetime years.

Application	Business as usual (years)	Increased battery removability (years)
Low-end smartphone	2.5	2.8
Mid-range smartphone	3	3.4
High-end smartphone	3.5	3.9
Tablets	5	5.4

3.3. IMPACTS ON DEVICE REPLACEMENT

Regulating battery removability and replaceability can reduce the unnecessary replacement of devices by 39 million units in 2030. This estimation assumes that the reduced replacement rate is a consequence of product life extension (see Table 5).

Application	Business as usual (million units sold)		Increased battery removability (million units sold)
	2020	2030	2030
Low-end smartphone	54	48	36
Mid-range smartphone	45	44	32
High-end smartphone	39	44	33
Total Smartphones	**138**	**136**	**101**
Tablets	24	23	19
Total devices	**162**	**159**	**120**

TABLE 5 Millions of units sold in 2020 and forecasted sales for 2030.

3.4. ENVIRONMENTAL SAVINGS

The GHG emission reductions from increasing battery removability in phones and tablets in the EU are significant (see Table 6). If by 2030 every new phone and tablet in the EU has easy to remove and replace batteries, reductions in carbon emissions would be 674,834 tons CO2e per year, which corresponds to a reduction by 30% compared to business as usual (see Table 6). This is equivalent to removing 456,603 passenger vehicles from the roads for one year or to providing electricity to 595,293 EU homes for one year.

TABLE 6 EU total greenhouse gas (GHG) emissions of new products sold in 2030 over one year of use.

Scenario	Business as usual	Increased battery removability
Smartphones GHG (tons CO2e)	2,015,554	1,389,950
Tablets GHG (tons CO2e)	247,020	197,790
Total GHG (tons CO2e)	**2,262,574**	**1,587,740**
GHG savings	**-**	**674,834**

Over their lifetime (2.8 to 3.9 years for phones and 5.4 years for tablets) emission reductions of all cellphones and tablets sold in the EU in 2030 would amount to 1.5 million tons CO2e (see Table 7). This is equivalent to removing 1 million passenger vehicles from the roads for one year or to providing electricity to 1.4 million EU homes for one year.

TABLE 7 EU total greenhouse gas (GHG) emissions of new products sold in 2030 over their lifetime.

Scenario	Business as usual	Increased battery removability
Smartphones GHG (tons CO2e)	6,143,600	4,752,017
Tablets GHG (tons CO2e)	1,235,100	1,068,066
Total GHG (tons CO2e)	**7,378,700**	**5,820,083**
GHG savings	**-**	**1,558,617**

In addition to the environmental benefits of extending the life of devices by improving battery removability and replaceability, there are also energy savings to be seen by facilitating battery repurposing. As mentioned in section 5.2.1, it is estimated that most portable rechargeable batteries are discarded with considerable remaining energy storage capacity. Based on estimations performed by German-Indian start-up company NUMAN we can assume that, theoretically, the usable capacity left after the first life of all smartphones, laptops, and e-bikes in stock in years 2016 and 2017 (depending on the product) could power 37,146 households in the EU (see Table 8).[37]

Application	Volume (year)	Capacity left after its "first life"/ Disposal	Theoretical remaining usable capacity (kWh)*	EU households that could be powered for a year**
Smartphone	1.47 BN (2016)	~ 65% 0.006 KWh	53,008,200	14,327
Laptop	150 M (2017)	~ 74% 0.048 KWh	432,000	117
E-bicycle	35 M (2016)	~ 80% 0.400 KWh	84,000,000	22,703
Total	**-**	**-**	**137,440,200**	**37,146**

TABLE 8 Theoretical energy capacity of portable batteries after their first life.

*Assuming 60% remaining usable SoH
** Based on 3,700[47] KWh annual electricity usage per household

3.5. ECONOMIC SAVINGS

Lifecycle costs – understood as those costs borne by the consumer – are negatively associated with longer product lifetimes as it is assumed that life extension reduces the need to invest in a new product.[5] As summarized in Table 9 below, improving battery removability and repairability of all new smartphones and tablets sold in 2030 would decrease the total consumer expenditure by 19.8 billion. These savings are assumed to be the result of reducing the sales of devices by 39 million units in 2030.

Scenario	Business as usual	Increased battery removability
Smartphones (million euros)	79.372	60.591
Tablets (million euros)	8.255	7.219
Total (million euros)	**87.627**	**67.811**
Cost savings	**-**	**19.816 million**

TABLE 9 Scenario comparison of total consumer expenditure of new smartphones and tablets sold in 2030.

3.6. SOCIETAL SAVINGS

Economic valuation of environmental impacts is used to estimate the level of damage incurred by society due to GHG emissions and the resulting climate change.[48] Societal costs are calculated using a 2019 methodology paper by the German Federal Environmental Agency[48] and are summarized in Table 10. Improving battery removability and repairability would decrease the lifetime societal costs of all new smartphones and tablets sold in 2030 by 725 million. This sum is four times larger than the 2020 EU budget allocated for climate-related expenditures.[49]

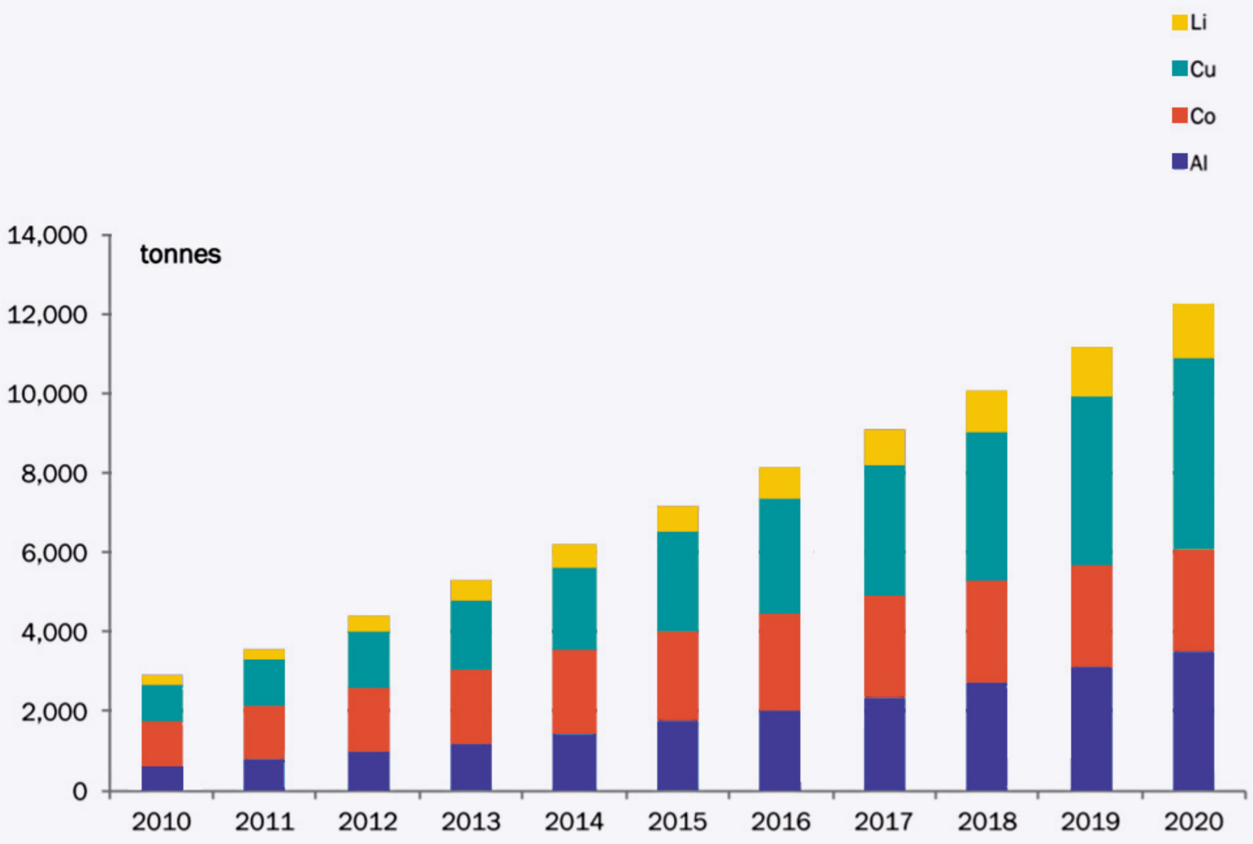
TABLE 10 Scenario comparison of lifetime societal costs of all new smartphones and tablets sold in 2030.

Scenario	Business as usual	Increased battery removability
Smartphones (million euros)	2.711	2.068
Tablets (million euros)	585	502
Total (million euros)	**3.296**	**2.571**
Cost savings	**-**	**725 million**

3.7. CRITICAL RAW MATERIALS

Product lifetime extension through circular strategies has potential for reducing critical raw material use in consumer electronics and LEVs.[6] A material flow analysis examining critical raw materials and circular strategies found that reused laptops and smartphones resulted in lower losses of critical raw materials like cobalt, rare earth elements and indium, versus recycling and replacement with new devices.[50] As recycling rates for many critical raw materials remain low, extending the lifetime of these devices is an effective measure to reduce losses of these materials. Batteries themselves also contain critical raw materials such as lithium, cobalt and graphite. Materials like lithium and graphite are not currently recovered in recycling processes and so are lost after use; circular strategies for the batteries could extend the use of these materials.[51] Others, like cobalt, can be recovered if collected and sent to battery recycling processes, so high recovery is dependent upon effective collection and removal of these batteries.[52]

FIGURE 21 **Selected elements in the waste batteries theoretically available for collection in 2010 – 2020, EU28+2, in tonnes.**
Source: Huisman et al., 2017.



4. Industry concerns

KEY POINTS

- Modular designs and reversible casing and joining techniques do not compromise ingress protection, weight, or safety requirements.
- Like other repairs, information can be provided so that repairers can appropriately assess their ability to conduct the repair or whether to bring the device to professionals. Accessible designs can enable safer repairs for such professionals.

Although there is general support towards increasing the sustainability of electronic devices, some manufacturers have argued that integrated batteries will lead to thicker, less durable designs. The argument is that integrated batteries are essential for waterproof designs and require less space to deliver the same performance level as their user-removable counterparts, which are features consumers want. One concern is that modular and easy-to-replace battery designs would require more materials, leading to thicker products.

However, information collected by Cordella et al. (2021) revealed that: 1) there is no correlation between battery capacity and modularity, and 2) the smartphones on the market with easy-to-replace batteries have comparable weights and dimensions to their fully integrated counterparts. As seen in Table 11, which is organized in ascending order based on battery capacity, there is no noticeable difference in battery capacity between a modular phone (SHIFT6m with 4200 mAh) and a non-modular phone (Galaxy Note10+ with 4300 mAh). Similarly, Table 12 shows no significant difference in the weight nor the percentage of the battery weight in relation to the total weight of the device between modular and non-modular phones.

modular devices

Smartphone model	Battery capacity (mAh)
iPhone 8	1821
iPhone 7	1960
Fairphone 2*	2440
SHIFTSme*	2450
Galaxy JS	2600
iPhone 10	2716
Fairphone 3*	3060
Xiaomi Mi 9	3300
Huawei P30 Pro	4200
SHIFT6m*	4200
Galaxy Note10+	4300

TABLE 11 Battery capacity associated with different modular and not modular devices.
Source: Cordella et al, 2021

Brand	Number of models assessed	Range in weight	Percentage of battery weight in relation to total weight of the device
Huawei	32	142.4 g to 232 g	25-30%
Apple	15	112 g to 208g	25-40%
Fairphone	1 (Fairphone 2)	168 g	22%

TABLE 12 **Battery weights associated with different modular and non modular devices.**
Adapted from Cordella et al., 2021.

Another industry concern is that LIB batteries are prone to combustion or explosion when they are damaged (i.e. the battery case is punctured). To avoid a safety incident, the manufacturers build very strong casings that use welding and glues to protect the battery from being damaged. However, there is evidence that battery packs can be designed to be repaired without compromising safety. Some models of Panasonic's e-bike battery packs are designed to be difficult to open for consumer but easy for professionals through the use of specialized (yet accessible) tools and easily replaceable cells.[7] Like other repairs, information can be provided so that repairers can appropriately assess their ability to conduct the repair or whether to bring the device to professionals. Accessible designs can enable safer repairs for professionals.

Another example is battery technology firm Aceleron[53] which has successfully designed LIBs for electric mobility and energy storage that can be repaired and upgraded, by allowing individual cells to be replaced or recycled.[8] This has been achieved by replacing the traditional welding and use of adhesives with a compression-based approach to assembling batteries that relies on fasteners to connect the parts.[8] Given the similarities in battery design that are shared between electric cars, LEVs, and some consumer electronics, it is realistic to assume that repairable battery packs for LEVs and consumer electronics is possible. The upcoming Battery Regulation presents an opportunity to incentivize and scale design innovations based on circular economy principles.

BATTERY COLLECTION

KEY CHALLENGES FOR BATTERY COLLECTION

- VARIETY OF SHAPES
- LACK OF MARKING
- INTEGRATED BATTERIES
- GLUES ADHESIVES
- PROPRIETARY TOOLS
- SMALL SIZES
- FIRES AND DAMAGE TO PROPERTY

80%

80% of batteries at waste facilities are removed manually.

11%

In Sweden in 2017, only 11% of the LIBs available for collection were collected.

LI-ION

The results show that the collection rate of LIBs is significantly lower than that of any other battery type.

1/3

From over 100 companies in 20 EU countries, one third of recyclers reported very serious fire incidents in connection with defective LIBs.

€ 190,000

An EU-wide survey revealed that the average cost of severe incidents in 2018 alone was estimated at EUR 190,000.

5. Conclusions

This study found that current battery designs for consumer electronics and LEVs increasingly use custom-made LIBs as well as adhesives and solder to seal battery packs and join LIBs into electronic devices. These techniques make it difficult for users and professionals to remove batteries without risking damaging the device's battery or other components. In addition to inaccessible battery designs, users and professionals are faced with software blocks and a lack of spares when trying to repair, replace, or repurpose batteries. Moreover, difficult to remove batteries result in low collection rates, which has increased the number of safety incidents in waste management facilities. As a result, LIBs that could be repaired or repurposed are being discarded and very few LIBs are being collected to recover and recycle valuable materials. Similarly, consumer electronics and LEVs that are otherwise functional are being replaced and prematurely turned to waste.

The market for rechargeable LIBs in consumer electronics is projected to more than double while the global demand for LIBs is projected to grow by 15% by 2030. Therefore, ensuring battery removability and replaceability is imperative to safeguard the environment, economy, and society from the devasting impacts of producing and discarding batteries. Facilitating battery removability would significantly improve battery repairability and reusability. Improved removability can be achieved through modular design of battery packs, standardization of cell designs (to allow easier exchange), and easy disassembly (i.e., using nuts and bolts to assemble the pack instead of welding or glue or holding cells in place with means other than potting or thermo-setting compounds).[45] Moreover, improving battery removability and replaceability will reduce the time and cost for repairers and recyclers, reduce consumer expenditure, GHG emissions, and societal costs.

Industry stakeholders commonly refer to a trade-off between durability and reparability, alluding to the fact that increasing modularity will affect the durability of the device. However, this study presented evidence that confirmed that modular designs and reversible case and battery joining techniques do not compromise ingress protection or weight requirements. Therefore suggesting that industry concerns are unsubstantiated and the EU should push manufacturers to design serviceable batteries in consumer electronics and LEVs as it will benefit society, the environment, and the economy.

6. Recommendations for a battery removability clause

Based on the findings presented in this report, the EEB and the Right to Repair campaign suggest the following additions (formatted in *red*, underlined, and in *italics*) for Article 11 of the upcoming Battery Regulation.

1. Portable batteries, *including light means of transport*, incorporated in appliances *or vehicles* shall be readily removable and replaceable by the end-user or by independent operators during the lifetime of the appliance *or vehicle*, if the batteries have a shorter lifetime than the appliance, or at the latest at the end of the lifetime of the appliance.

Portable batteries incorporated in appliances should not use nonreversible battery joining techniques that require specialized tools, thermal energy, or solvents to disassemble.

Portable battery packs and the cells within the packs incorporated in appliances should be easily disassembled by independent operators with specialized but available tools.

A battery *pack or battery cell within a battery pack* is readily replaceable *when it can be removed with tools commonly available to the end user; and* where, after its removal from an appliance, it can be substituted, *with tools commonly available to the end user*, by a similar battery without affecting the functioning or the performance of that appliance.

2. *From the moment that a battery model is supplied within the territory of a Member State producers shall make available electronically, to end-users and independent operators, easily understandable information regarding battery pack and battery cell replaceability and removability including:*

- **a.** *Step-by-step information to ensure safe battery pack and battery cell removal and replacement*
- **b.** *The provision of software tools, firmware, and other necessary means such as remote authorization of serial numbers to enable full functionality of the battery and the device after repair*
- **c.** *Information about access and cost of spare parts*

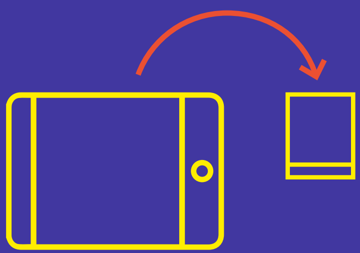
3. *From the moment that a battery model is supplied within the territory of a Member State and until seven years after placing the last unit of the model on the market, producers shall provide batteries to end-users as spare parts, and key components for battery repair, including cells and electronic boards, should be available as spare parts to independent operators. Producers should also enable full functionality of the batteries after repair, including remote authorization of software resets.*

4. The obligations set out in paragraph 1 shall not apply where:

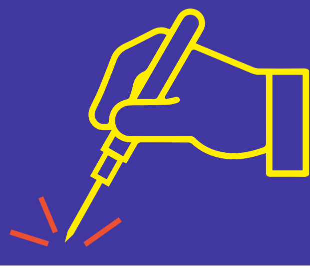
a) continuity of power supply is necessary and a permanent connection between the appliance and the portable battery is required for safety, performance, medical or data integrity reasons; or
~~b)) the functioning of the battery is only possible when the battery is integrated into the structure of the appliance~~

5. The Commission shall adopt guidance to facilitate harmonised application of the derogations set out in paragraph *4*.

KEY POLICY RECOMMENDATIONS

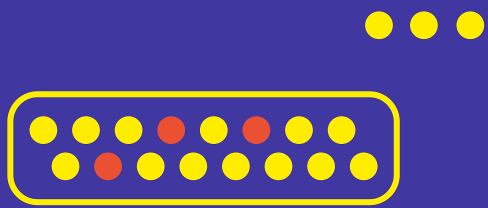


Make all batteries in consumer electronics and LEVs removable and replaceable by citizens and independent repairers.



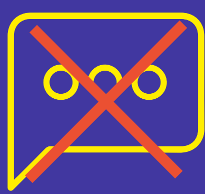
Make all battery packs repairable by independent professionals.

Prohibit the integration of batteries in consumer electronics using glues, welding or other techniques.



Make spare parts for battery repair available to independent repairers.

Prevent the use of software blocks which disable battery replacement or repair.



Avoid exemptions/derogations which give loopholes to requirements.

REFERENCES

1. Van Leipsig J. 9 facts about refurbishing e-bike batteries. Bike Europe. Published 2021. https://www.bike-eu.com/products-innovations/nieuws/2021/02/9-facts-about-refurbishing-e-bike-batteries-10139863

2. Sylvester L. Repairing And Rebuilding Electric Bike Batteries (Refurbishing Guide). e-biking Today. https://www.ebikingtoday.com/repairing-rebuilding-electric-bike-batteries-refurbishing-guide/

3. Stahl H. *Study Report in Support of Evaluation of the Directive 2006/66/EC on Batteries and Accumulators and Waste Batteries and Accumulators: Final Evaluation Report : Under the Framework Contract on Economic Analysis of Environmental and Resource Efficiency Policies ENV.F.1./FRA/2014/0063*. Publications Office; 2018. Accessed October 1, 2021. https://data.europa.eu/doi/10.2779/109186

4. Talens Peiró L, Ardente F, Mathieux F. Design for Disassembly Criteria in EU Product Policies for a More Circular Economy: A Method for Analyzing Battery Packs in PC-Tablets and Subnotebooks. *Journal of Industrial Ecology*. 2017;21(3):731-741. doi:10.1111/jiec.12608

5. Karsten Schischke, Christian Clemm, Anton Berwald, et al. *Ecodesign Preparatory Study on Mobile Phones, Smartphones and Tablets: Final Report*. Publications Office; 2021. Accessed October 1, 2021. https://data.europa.eu/doi/10.2873/175802

6. Mathieux F, Ardente F, Bobba S, et al. *Critical Raw Materials and the Circular Economy: Background Report*. Publications Office; 2017. Accessed November 15, 2021. https://data.europa.eu/doi/10.2760/378123

7. Jean-Pierre Schweitzer. Personal communication with Presta Batterie. Published online November 2021.

8. Jones S. 5 minutes with Aceleron's Carlton Cummins. Management Today. Published January 26, 2020. https://www.managementtoday.co.uk/5-minutes-acelerons-carlton-cummins/smes/article/1461718

9. Cordella M, Alfieri F, Clemm C, Berwald A. Durability of smartphones: A technical analysis of reliability and repairability aspects. *Journal of Cleaner Production*. 2021;286:125388. doi:10.1016/j.jclepro.2020.125388

10. Stahl, Oeko Institut., Ramboll., Umweltbundesamt. *Assessment of Options to Improve Particular Aspects of the EU Regulatory Framework on Batteries: Final Report*. Publications Office; 2020. Accessed October 1, 2021. https://data.europa.eu/doi/10.2779/432234

11. Albertsen L. *Circular Business Models for Electric Vehicle Lithium-Ion Batteries: An Analysis of Current Practices of Vehicle Manufacturers in the EU and the Potential for Innovation at Volvo Group*. The International Institute for Industrial Environmental Economics; 2020.

12. Dühnen S, Betz J, Kolek M, Schmuch R, Winter M, Placke T. Toward Green Battery Cells: Perspective on Materials and Technologies. *Small Methods*. 2020;4(7):2000039. doi:10.1002/smtd.202000039

13. Jean-Pierre Schweitzer. Personal communication with Batterie Express. Published online November 2021.

14. Jean-Pierre Schweitzer. Personal communication with Daurema. Published online October 2021.

15. Herreras-Martinez L, Anta M, Bountis R. Recommendations for tackling fires caused by lithium batteries in WEEE. A report of the Batteries Roundtable. Published online 2021.

16. Ollion L, Anta M, Herreras L. Characterisation of fires caused by batteries in WEEE: Survey results from the WEEE management chain – part A, a WEEE Forum and EuRIC report. Published online 2020.

17. Nigl T, Rübenbauer W, Pomberger R. Cause-oriented investigation of the fire incidents in Austrian waste management systems. *Detritus*. 2019;9:213-220. doi:10.31025/2611-4135/2019.13872

18. Parajuly K, Kuehr R, Awasthi AK, et al. *Future E-Waste Scenarios*. StEP, UNE ViE-SCYCLE & UNEP IETC; 2019.

19. Olivetti EA, Ceder G, Gaustad GG, Fu X. Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. *Joule*. 2017;1(2):229-243. doi:10.1016/j.joule.2017.08.019

20. Circular Energy Storage. The Li-ion battery lifecycle sample report 2021. Published online 2020.

21. Global Battery Alliance, World Economic Forum. A vision for a sustainable battery value chain in 2030. Published online 2019.

22. European Commission. Proposal for a Regulation of the European Parliament and the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020. Published online 2020.

23. Tsiropoulos I, Tarvydas D, Lebedeva N. *Li-Ion Batteries for Mobility and Stationary Storage Applications: Scenarios for Costs and Market Growth*. Publications Office; 2018. Accessed October 25, 2021. https://data.europa.eu/doi/10.2760/87175

24. Maximize Market Research PVT LTD. *E-Bike Market: Global Key Industry Trends and Outlook 2027.*; 2021. https://www.maximizemarketresearch.com/market-report/global-e-bike-market/36655/#toc

25. Precedence Research. Electric Scooters Market Size Surpass Around US$ 33.5 Bn by 2030. GlobalNewswire. Published September 15, 2021. https://www.globenewswire.com/en/news-release/2021/09/15/2298018/0/en/Electric-Scooters-Market-Size-Surpass-Around-US-33-5-Bn-by-2030.html

26. Battery University. BU-216: Summary table of Lithium-based Batteries. Published 2021. https://batteryuniversity.com/article/bu-216-summary-table-of-lithium-based-batteries

27. Yang J, Gu F, Guo J. Environmental feasibility of secondary use of electric vehicle lithium-ion batteries in communication base stations. Resources, Conservation and Recycling. 2020;156:104713. doi:10.1016/j.resconrec.2020.104713

28. Lee P, Casey M, Wigginton C. Technology, media, and telecomunication predictions in 2020. Published online 2020. https://www2.deloitte.com/us/en/insights/industry/technology/technology-media-and-telecom-predictions/2020/bike-technology-transformation.html

29. Research and Markets. World Electric Scooters Market Size, Share & Trends Analysis & Forecasts Report 2021. Businesswire. Published August 11, 2021. https://www.businesswire.com/news/home/20210811005691/en/World-Electric-Scooters-Market-Size-Share-Trends-Analysis-Forecasts-Report-2021-2028---ResearchAndMarkets.com

30. George N. Everything you need to know about e-bike batteries [from a battery engineer]. som-EV. Published 2021. https://www.som-ev.com/blog/everything-about-e-bike-batteries-from-a-battery-engineer

31. Foley D. Electric scooter batteries: Everything you need to know. Scooter.guide. Published 2021. https://scooter.guide/electric-scooter-batteries-everything-you-need-to-know/

32. Fowler G. Everyone's AirPods will die. We've got the trick to replacing them. Washington Post. https://www.washingtonpost.com/technology/2019/10/08/everyones-airpods-will-die-weve-got-trick-replacing-them/. Published 2019.

33. Leswing K. Apple AirPod batteries are almost impossible to replace, showing the need for right-to-repair reform. CNBC. https://www.cnbc.com/2021/07/10/apple-airpod-battery-life-problem-shows-need-for-right-to-repair-laws.html. Published July 10, 2021.

34. iFixit. AirPods Pro Teardown. iFixit. Published 2019. https://www.ifixit.com/Teardown/AirPods+Pro+Teardown/127551

35. Philipson N, Wallner A. Urbanears Modular: An adaptable headphone system to extend lifetime. Published online 2018. https://hdl.handle.net/20.500.12380/256088

36. ECOS, Coolproducts for a cool planet, European Environmental Bureau, RReuse, Right to repair, HOP. Comments on the preparatory study proposals for Ecodesign and Energy Labelling requirements on smartphones and tablet. Published online 2021.

37. Chatterjee P. Second-life battery: Green power from used batteries. NUMAN. Published 2020. https://www.audi-umweltstiftung.de/umweltstiftung/en/projects/greenovation/nunam.html

38. Chatterjee P. Solarbox Project: making energy accessible to all. Presented at: Energy Futures Lab - Imperial College London; 2019. https://imperialcollegelondon.app.box.com/s/gkcw3764izrhwk0qjduduwgb8p613y6x

39. Zhao Y, Pohl O, Bhatt AI, et al. A Review on Battery Market Trends, Second-Life Reuse, and Recycling. Sustainable Chemistry. 2021;2(1):167-205. doi:10.3390/suschem2010011

40. Winzer J, Czichowski J, Lascho T, et al. Constomer acceptance of mobile devices with permanently installed batteries and accumulators. In: Proceedings, Final Edition. Fraunhofer Institute; 2020:179-183. Accessed September 18, 2021. https://online.electronicsgoesgreen.org/papers/

41. Melin HE. State-of-the-art in reuse and recycling of lithium-ion batteries – A research review. Published online 2018:57.

42. Huisman J, Leroy P, Tertre F, et al. Prospecting Secondary Raw Materials in the Urban Mine and Mining Wastes (ProSUM) - Final Report.; 2017. http://www.urbanmineplatform.eu/wasteflows/batteries/percentage

43. ProSum. Urban Mine Platform. http://www.urbanmineplatform.eu/wasteflows/batteries/percentage

44. Brown M, Hilton M, Crossette S, et al. Cutting Lithium-Ion Battery Fires in the Waste Industry. Eunomia, Environmental Services Association; 2021. https://www.eunomia.co.uk/reports-tools/cutting-lithium-ion-battery-fires-in-the-waste-industry/

45. Gaines L, Richa K, Spangenberger J. Key issues for Li-ion battery recycling. MRS energy sustain. 2018;5:e14. doi:10.1557/mre.2018.13

46. Coughlan D, Fitzpatrick C, McMahon M. Repurposing end of life notebook computers from consumer WEEE as thin client computers – A hybrid end of life strategy for the Circular Economy in electronics. Journal of Cleaner Production. 2018;192:809-820. doi:10.1016/j.jclepro.2018.05.029

47. Odyssee-Mure. Electricity consumption per dwelling. Published February 2021. https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html

48. Matthey A, Björn B. Methodological Convention 3.0 for the Assessment of Environmental Costs. Published online 2018.

49. European Commission. Directorate General for Climate Action., Ricardo Energy & Environment., IEEP., Trinomics., ClimateKos. Climate Mainstreaming in the EU Budget: Preparing for the next MFF : Final Report. Publications Office; 2017. Accessed October 29, 2021. https://data.europa.eu/doi/10.2834/218038

50. Ljunggren Söderman M, André H. Effects of circular measures on scarce metals in complex products – Case studies of electrical and electronic equipment. Resources, Conservation and Recycling. 2019;151:104464. doi:10.1016/j.resconrec.2019.104464

51. Charles RG, Douglas P, Dowling M, Liversage G, Davies ML. Towards Increased Recovery of Critical Raw Materials from WEEE– evaluation of CRMs at a component level and pre-processing methods for interface optimisation with recovery processes. Resources, Conservation and Recycling. 2020;161:104923. doi:10.1016/j.resconrec.2020.104923

52. Buchert M, Manhart A, Bleher D, Pingel D. Recycling Critical Raw Materials from Waste Electronic Equipment. Oeko-Institut; 2012. https://www.oeko.de/oekodoc/1375/2012-010-en.pdf

53. The essential, dependable, scalable power. Aceleron. https://www.aceleronenergy.com/

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The European Right to Repair Campaign is a coalition including over 85 members from 18 countries. Our members represent community repair groups, environmental activists, social economy actors, self repair advocates, repair professionals, businesses and any citizen who would like to obtain their right to repair. We're fighting to remove the barriers to repair our products, so they can last for longer. We're asking for a universal right to repair, making all products easier and affordable to repair by everyone.

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