



## Position paper of Environmental Action Germany

Resource efficiency for electric vehicle batteries: Strengthening ecodesign, reuse, repair and high-quality recycling

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## Profile of Deutsche Umwelthilfe e.V. (DUH) (Environmental Action Germany)

Environmental Action Germany is a recognized German environmental and consumer protection association that has been actively campaigning for the preservation of our natural resources and the interests of consumers since 1975. We are politically independent, non-profit and active at national and European level. We are known, for example, for our role in uncovering the diesel scandal and introducing a deposit system for single-use beverage packaging in Germany. In the area of circular economy, we are committed to waste prevention, responsible consumption and a sustainable economy. Further information can be found at [www.duh.de/englisch](http://www.duh.de/englisch).

## Introduction

The shift towards battery-powered vehicles plays a crucial role in reducing CO<sub>2</sub> emissions and air pollution in the transport sector. In the overall assessment, electric vehicles have a lower climate and environmental impact than comparable combustion vehicles.<sup>1</sup> However, electric vehicles are not a panacea, as their production, use and disposal also have an environmental impact. For example, the production of lithium-ion batteries (LIB) requires raw materials such as lithium, cobalt and nickel, the extraction of which is associated with significant environmental impacts (e.g. high consumption of water resources, release of pollutants and impact on ecosystems). It is therefore crucial to ensure that the energy transition does not merely lead to a **shift in environmental impacts**. Consistent implementation of the waste hierarchy has great potential to drastically reduce the environmental impact of electric vehicle batteries (EV batteries).

The **waste hierarchy** is an order of priority set out in the EU Waste Framework Directive, which should guide all legislation in the area of the circular economy. It stipulates that prevention and (preparation for) reuse<sup>2</sup> should be given priority over recycling and recovery in order to minimize

adverse environmental impacts. As a result, there is significant potential to increase the resource efficiency of EV batteries particularly in the upper levels of the waste hierarchy, e.g. by reducing demand, promoting smaller and lighter batteries, substituting critical materials and advancing repair, reuse and effective collection as a prerequisite for high-quality recycling. Only a holistic approach with measures at all levels of the waste hierarchy can effectively minimize the environmental impact of EV batteries.



Waste hierarchy from the Waste Framework Directive

## Insufficient integration of the waste hierarchy into European legislation

DUH believes that both existing legislation and current legislative proposals take insufficient account



of the waste hierarchy and neglect essential resource efficiency measures.

The **EU Batteries Regulation** adopted in June 2023 sets out for the first time clear requirements for the entire life cycle of EV batteries, such as limiting greenhouse gas emissions during production or regulating the use of recycled materials. However, decisive measures to promote a long service life, repair and reuse structures as well as binding ecodesign specifications (reparability, reusability and recyclability) are missing.<sup>3</sup>

The latest agreement reached by the EU institutions on the Critical Raw Materials Act (**CRMA**) in December 2023 also fails to achieve the goal of reducing resource dependencies through effective circular economy and the efficient use of primary raw materials.<sup>4</sup> Instead of prioritizing waste prevention, repair and reuse, the focus is on promoting recycling as the third stage of the waste hierarchy.

The EU Commission published a proposal for a regulation on circularity requirements for vehicle design and on management of end-of-life vehicles (VDEoL) in July 2023. The draft lacks measures to reduce vehicle size, waste prevention and concrete ecodesign requirements, although the proposed regulation aims to make the design of vehicles more sustainable. This is particularly problematic as the current trialogue decision for an Ecodesign for Sustainable Products Regulation (**ESPR**) excludes vehicles completely.

An important opportunity to strengthen the upper waste hierarchy for EV batteries would be a "**right to repair**". Important elements here are, for example, a repair-friendly design and good availability of spare parts and software updates. A proposal for an EU-wide right to repair is currently in the

trialogue process. From DUH's point of view, this directive in its current form will not be able to enable a manufacturer-independent right to repair.<sup>5</sup>

The deficits described regarding implementation of the waste hierarchy in current legislation pose a major problem. As the production capacities for EV batteries are increasing rapidly due to mobility shift required by climate policy, important legal framework conditions should now be created quickly in order to effectively limit the ecological consequences of the increasing resource requirements.



The implementation of the waste hierarchy in current legislation has decisive deficits

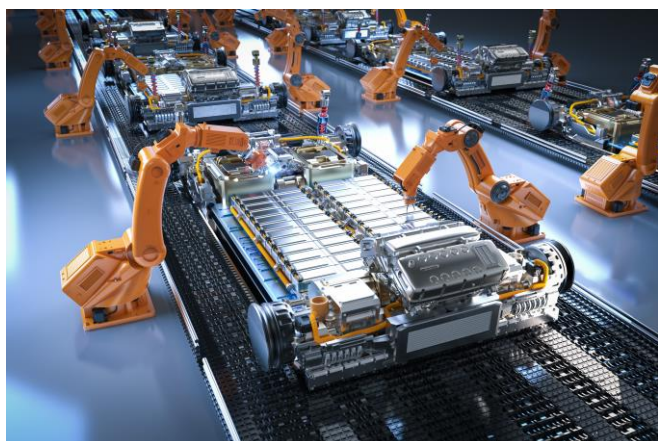
This paper presents necessary measures to strengthen the upper levels of the waste hierarchy in the field of electric EV batteries. It analyzes environmental potentials, addresses possible obstacles and shows solutions for an effective implementation of the measures.

## Measures to promote the resource efficiency of electric vehicle batteries at the upper levels of the waste hierarchy

### 1. Improvements in ecodesign

The life cycle assessment of EV batteries is already significantly influenced during the design and manufacturing phase. The production of conventional

LIBs requires the energy and environmentally intensive extraction of a large number of critical raw materials such as lithium, cobalt and nickel. In addition, the production of these batteries generates greenhouse gas emissions of 40 - 350 kg CO<sub>2</sub> per kWh of battery capacity.<sup>6</sup> It is therefore crucial to ensure that EV batteries are used as long as possible in order to spread these environmental impacts over a long period of use. A low battery weight also plays a decisive role. Relevant aspects for the resource-efficient ecodesign of EV batteries are therefore the environmentally friendly use of raw materials, a long service life and good reparability, reusability and recyclability.



The ecodesign of EV batteries must be enshrined in law

The new **EU Batteries Regulation** sets out some welcome ecodesign requirements for EV batteries, such as recycled content targets (Article 8) and requirements for electrochemical performance and durability (Article 10). In DUH's view, however, these provisions must be supplemented by further ecodesign aspects and relevant details must be specified in delegated acts.

### Economical use of raw materials

As few primary raw materials as possible should be used in the production of EV batteries and the materials used should have the lowest possible environmental impact in the countries of origin. The

use of particularly problematic materials, such as cobalt or lithium, should be minimized as far as possible in battery production. Against this background, the current trend towards a continuous increase in the weight of vehicles and EV batteries is highly problematic.<sup>7</sup> However, new battery technologies that substitute critical raw materials can have positive effects (see section 7).

In order to address these points, DUH proposes first establishing a **monitoring** system to better record the raw material requirements in the production of EV batteries. All raw materials used, their recycled content and the countries of origin of the primary raw materials should be disclosed, for example via the part of the battery passport that can also be viewed by consumers. In the opinion of DUH, the transparency obligations set out in Article 8 (1) of the EU Batteries to apply from 2028, do not go far enough.

Following this monitoring, a possible **limitation of the use of primary raw materials** in battery production should be investigated, for example in relation to the total battery weight (e.g. as a fleet limit) or by limiting the mass of certain particularly problematic raw materials. There may also be specifications for a product/fleet-specific material footprint. Corresponding regulations are missing in the EU Batteries Regulation, in the draft for the VDEoL and are not planned for the ESPR either.

### Recycled content

The use of **recycled content** in manufacturing can contribute significantly to reducing the environmental impact of products. Secondary materials such as steel, aluminum, cobalt and nickel are already available on the market for EV batteries<sup>8</sup>, but high-quality recycling processes for used batteries and the use of these recyclates for battery

production must be further promoted. In particular, the use of secondary lithium, which is currently often only recovered in small proportions from battery recycling, plays a decisive role, as the battery cell technologies established on the market are based on this raw material and demand is increasing drastically.<sup>9</sup> In Article 8(2) of the EU Batteries Regulation, recycled content targets for lithium, lead, cobalt and nickel in EV batteries will be legally required for the first time from 2032 on and increased again from 2036. This is an important signal for the recycling industry to build up corresponding capacities. From DUH's point of view, however, a decisive aspect here is the calculation method: waste from battery production (post-industrial recycled content (PIR)) should not be included in the recycled content targets so that this measure actually promotes the use of post-consumer recycled content (PCR), the recycling of which is currently still economically unattractive.

There is also considerable potential in the use of recycled plastics, which is why binding targets for the use of plastic recyclates in EV batteries should also be set. The EU draft of the VDEoL (13.07.2023) proposes such targets for vehicles for the first time, but the regulation would not apply to batteries. When calculating recycled content targets for plastics, it should also be noted that pyrolysis or gasification technologies should not be included.<sup>10</sup>

## Durability

A high durability is a key aspect for the sustainability of EV batteries, as it reduces the environmental impact of resource consumption, production and disposal through a longer service life. Durability of EV batteries is also an important basis for the profitability of reuse or repair structures. Batteries should be designed in such a way that they are insensitive to certain defects or rapid wear and tear.

DUH is calling for a legally guaranteed **minimum service life of 15 years**, so that under normal use at the end of this period, a residual capacity of 80 percent is still available.

Since the usage and **charging behavior** of some battery chemistries (e.g. LIBs) also has a very significant influence on wear<sup>11</sup>, careful charging behavior should be promoted through charge management and information for consumers.<sup>12</sup> There is also considerable potential to enhance durability through alternative battery technologies, since e.g. the lithium iron phosphate battery has better charging and discharging efficiency and therefore a longer service life than lithium-ion batteries.<sup>13</sup>

The **EU Batteries Regulation** (Article 10) is an important foundation for regulating the performance and durability of EV batteries. Parameters such as capacity loss and the expected service life of the battery will be limited. These specifications must now be specified in delegated acts as quickly as possible so that they become timely effective.

## Reparability

Good reparability is an important basic requirement for a long service life of EV batteries and their reuse. It must therefore be taken into account in



Exploiting the potential of resource conservation through repair

the design of the battery. The EU Batteries Regulation (Article 77 or Annex XIII) contains requirements for manufacturers to provide information on dismantlability. However, DUH believes that this is not sufficient to ensure good reparability. This would require design specifications that stipulate a modular structure and the **removability and replaceability of individual battery modules**. The safety concerns frequently cited by the industry with regard to interchangeability at cell level should be scientifically examined by the EU Commission in order to avoid giving away the resource-saving potential of such repairs. In this context, the often-applied integration of so-called cell-to-pack modules in production is problematic, as it makes repair considerably more difficult.

Article 7 of the draft VDEoL (13.07.2023) contains individual provisions on the **removability and replaceability of EV batteries**, such as ensuring the non-destructive removal of the battery from the vehicle. However, the requirements should not be limited to the end of the vehicle's life. EV batteries must also be able to be removed and replaced easily and non-destructively during use, especially for the purposes of repair and reuse. Other important measures to promote repair are presented in section 3.

### Reusability

First and foremost, the reuse of EV batteries requires good technical prerequisites. For this, subsequent reuse must be taken into account in the design process from the outset. Important criteria here are, for example, a long service life, a modular design that is as standardized as possible and good dismantling and reparability. There should also be a ban on software blocks making reuse more diffi-

cult. Further measures to promote reuse - particularly with regard to the necessary data provided by manufacturers - are presented in section 2.



Modular design of an EV battery can improve reparability and reusability

### Recyclability

Recyclability is an important sustainability criterion, as it helps to close raw material cycles and reduces the use of primary resources. It must therefore be taken into account during the design of EV batteries, without neglecting criteria such as durability, reparability and reusability. Important measures to promote the recyclability of EV batteries include promoting a good dismantlability of battery components (e.g. by avoiding material composites), the use of uniform materials, good labeling and a low level of pollutants and impurities.

For the first time, the **EU Batteries Regulation** sets out requirements for the labeling of batteries, e.g. with regard to the chemical composition and the hazardous substances and critical raw materials contained (Article 13). Information on dismantling is to be provided via the battery passport (Article 77 or Annex XIII). These welcome requirements must now be quickly put into practice and supplemented by binding requirements for recycling-friendly battery design.



## Standardization

Further development of standardization in the field of EV batteries and corresponding components is necessary to improve resource efficiency. The EU Batteries Regulation completely lacks provisions to promote a standardized structure and design of EV batteries and components. The draft for a VDEoL (13.07.2023) also does not contain any approaches to promote a standardized design of EV batteries.

The standardization of batteries and associated components can make it easier for them to be used for several vehicle types and thus also supports their long-term availability. In addition, the subsequent upgrading of vehicles with newly developed batteries can be promoted, thus enabling a longer vehicle service life. In particular, a standardized design of EV batteries and cell packs is relevant for promoting the **reuse** of EV batteries, as



Further development of standardization can contribute to resource conservation

similar designs and functionalities significantly reduce the cost of second-life applications. Standardization should be supported as far as possible within the manufacturers' product lines, but also across manufacturers. Political instruments should promote these developments. In addition to construction and functionality, standardization is also necessary with regard to data formats that are

made available to actors in the fields of reuse, repair and recycling.

## Integration of ecodesign aspects into fee structures

License fees that are directly linked to the environmental impact of EV batteries can be a valuable instrument for promoting the aforementioned ecodesign criteria. This **eco-modulation** of license fees should be designed so effectively that manufacturers actually receive incentives to design products more in line with ecological criteria. Such fees should also be made visible to consumers and the link to ecodesign criteria should be clearly communicated (so-called visible fees) in order to influence purchasing behavior. DUH proposes parameters such as battery weight, durability, reparability, reusability, use of reused parts and recycled materials as well as recyclability as important parameters to consider during eco-modulation, e.g. through a bonus/malus system.

## 2. Promotion of reuse

At the end of their first life as a traction battery, EV batteries often still have a very good storage capacity of between 70 and 80 percent<sup>14,15</sup> and are therefore suitable for mobile or stationary use in second-life (SL battery). Possible second-life applications include energy storage systems for photovoltaic or wind power plants, emergency power systems in the municipal power grid or primary control power in power grid operation.<sup>16</sup> There will be a great demand for such energy storage systems in the future electricity grid due to the expansion of renewable energies. The potential of used EV batteries should therefore be exploited.



## Potential to reduce environmental impact through reuse

Reusing an electric vehicle battery is generally the more environmentally friendly option compared to recycling, as the environmental impact of raw material extraction, battery production and disposal compensated by a longer service life. For example, when a 160 kg LIB is reused, 10 kg manganese; 20 kg copper; 6 kg lithium; 8 kg cobalt; 29 kg nickel, 35 kg aluminum, 52 kg graphite remain in longer use<sup>17</sup>, which would only have been partially recovered if the battery had been recycled at an earlier date. As reuse reduces the need for newly produced batteries, the overall environmental impact is enormous, for example in terms of greenhouse gas emissions, water consumption, acidification and the consumption of abiotic resources.<sup>18</sup> Additionally, the energy required to recycle and produce a new battery can be delayed, resulting in significant energy savings<sup>19</sup>.

## Market for reuse

If the EU is to meet its declared goal of climate neutrality by 2050, an estimated 970 GWh of grid-wide installed battery storage capacity will be required by 2030. This would require a significant increase in annual additions, averaging almost 120 GW per year between 2023 and 2030.<sup>20</sup> It makes a lot of sense to fully exploit the potential of used EV batteries to meet this demand. In 2030, around 120,000 EV batteries from electric cars will be generated annually in the EU as end-of-life batteries, which have a storage capacity of approximately 8 GWh.<sup>21</sup> Companies have already recognized the **potential of second-life EV batteries**. Box 1 presents a selection of current business models in the field of vehicle battery reuse.

In addition, **insurance companies** are increasingly important players who, for example, are very interested in the reuse of vehicle parts such as EV batteries after an accident for cost reasons. A best-practice example is Sweden, where insurance companies are already cooperating with reuse players and strengthening the reuse spare parts market for electric vehicles.<sup>22</sup>

## Overcoming obstacles in practice

Automotive and battery manufacturers currently often prefer a rapid return of used batteries in order to recycle raw materials quickly, as there is an economic interest in the battery materials for new sales.<sup>23</sup> **The complexity of the reuse process**, e.g. due to a lack of data, different battery cell technologies and safety concerns, is also often cited as an argument as to why batteries are not suitable for reuse.<sup>24</sup> In particular, it is the **responsibility of producers** to provide the technical data required for safe reuse. In addition, poor dismantlability, a design that is difficult to repair and a large number of different battery formats and cell technologies make it difficult to prioritize environmentally friendly reuse. A "saturation" with regard to the development of battery cell technologies is not yet foreseeable, but will occur in the future, which will improve the ability to plan for reuse.<sup>25</sup> It is important to quickly overcome these practical obstacles to the reuse of EV batteries through policy instruments and market developments.

» **BeePlanet** (energy storage system production)

The Spanish provider BeePlanet manufactures energy storage systems that reuse EV batteries. The batteries are used for photovoltaic, wind and off-grid installations for e.g. the residential, commercial or industrial sectors. BeePlanet has direct agreements with automotive suppliers/manufacturers for the collection and reuse of used EV batteries. Further information can be found at <https://beeplanetfactory.com/en/>.

» **Connected Energy** (energy storage system production)

The British company Connected Energy designs and develops energy storage systems using used batteries from electric vehicles from automotive partners. Their second life systems have a range of applications including storing renewable energy and managing energy loads for electric vehicle charging stations for commercial, industrial and public authorities. Further information can be found at <https://connected-energy.co.uk/>.

» **Circunomics** (software and platform service provider)

The German company Circunomics offers software for analyzing the condition of used EV batteries and operates a marketplace for second-life and recycling. The platform supports the networking of stakeholders and promotes reuse applications for energy storage systems or micromobility, for example. Further information can be found at <https://www.circunomics.com/>.

» **Betteries AMPS GmbH** (manufacture of mobile energy systems)

The German company Betteries offers alternatives to fuel-powered generators by reprocessing used electric EV batteries at module level. The modular energy systems can be used in various industry segments such as the construction industry, civil and disaster protection, as well as the film and entertainment industry. Further information can be found at <https://betteries.com/>.

» **Watt4ever** (production of energy storage and drive systems and generators)

The Belgian company Watt4Ever offers high-quality second-life battery modules for private individuals and companies. The applications range from large storage systems to modules for electromobility or storage applications for companies. Further information can be found at <https://watt4ever.be/>.

*Box 1: Exemplary business models for second-life applications of EV batteries*

DUH does not see any contradiction between achieving **recycled content targets and reuse**: On the one hand, the amount of used batteries available for recycling is decreasing, but at the same time the demand for new batteries to be produced is also decreasing, so that the amount of recyclates available for new production should hardly be influenced by increased reuse. However, political instruments to promote recycling should be designed in such a way that they do not hinder reuse.

### Necessary measures to promote reuse

In addition to good technical prerequisites through ecodesign (see section 1), independent players need easily accessible **manufacturer information** for successful and economical reuse. To this end, they must collect the necessary technical data and make it available to independent stakeholders (e.g. basic technical data, data on dismantling, data on the "state of health"). This is the only way to ensure that important events that could affect the life and safety of the battery are properly taken into account when testing a vehicle battery for reusability. The EU Batteries Regulation contains initial welcome requirements for tracking harmful events, e.g. number of deep discharges, period under extreme temperatures, and period of charging under extreme temperatures (Article 14 and Annex VII). However, manufacturers should allow independent actors not only "read access" to the battery management system (BMS) (Article 14), but also **"control access"** in order to integrate the BMS into the second-life application and make optimal use of the batteries. Manufacturers should be legally obliged to provide all this data without financial and structural hurdles for independent players and in a standardized form. The battery passport is a useful instrument for this.

The EU Batteries Regulation specifies target values for the recycling efficiency and material recovery of EV batteries (Article 71), but there are no binding **reuse targets**. The current regulation results in a biased focus on recycling and contradicts the waste hierarchy. DUH calls for the introduction of such reuse targets, the specific level of which should be determined by the Commission on the basis of market data and should gradually increase. Furthermore, these targets should not only be mandatory for the Member States, but also for producers and their collective organisations. This would create appropriate incentives to create structures for reuse. To promote reuse, DUH also proposes introducing an **obligation to check the reusability** of used EV batteries before they are dismantled. In the case of reusability, the battery must be removed in a non-destructive manner and the battery must be given to (preparation for) reuse.

In Europe, the decision as to what happens to an accident-damaged vehicle is often in the hands of the **insurer**, but in Germany, it is up to the owner. As during the expansion of electromobility initially mainly batteries from accident vehicles are available for reuse, it may make sense to promote the role of insurance companies in order to strengthen



Reconditioned EV batteries are often still suitable for renewed stationary or mobile use in their "second life"



the spare parts market and cooperation with reuse players.

In order to establish reuse structures timely, **economic incentives** for more reuse should also be created. Possible instruments in this field would be tax reductions for repairs and the use of reused EV batteries. Public procurement should also commit to prioritizing the use of second-life batteries and make this a condition of funding programs for stationary energy storage systems. Rental and leasing programs that provide customers with reused batteries and thus enable long-term use could also be promoted.

### 3. Promotion of repair

Regular maintenance and repair significantly extends the service life of EV batteries and can sometimes prevent premature complete replacement. Repair reduces the need for batteries and thus minimizes the environmental impact associated with their production (e.g. resource requirements, energy requirements). Therefore, optimal conditions should be created for the repair of EV batteries.

#### Overcoming obstacles in practice

Currently, there is already a shortage of affordable repair solutions for EV batteries on the market, as there is a lack of **diagnostic infrastructure** to accurately diagnose the condition of EV batteries and identify appropriate repair options.<sup>26</sup> The lack of data and diagnostic capabilities makes it difficult particularly for insurers to make informed decisions about the repair of electric vehicles, which means that these vehicles are often disposed of prematurely.

The **cost of repairs** also plays a decisive role in the market for insurance companies and vehicle own-

ers to opt for a repair instead of a complete replacement of EV batteries. According to the German Insurance Association, repair costs for electric vehicles between 2019 and 2021 were 30 - 35 percent higher than for comparable combustion vehicles.<sup>27</sup> The current high costs are due to the low distribution of electric vehicles and safety measures for dealing with damaged lithium-ion batteries. However, the expansion of the market for electric vehicles and new types of batteries mean that these costs can be expected to fall in the future. Additionally, electric vehicles need to be repaired less frequently than comparable combustion engines, as fewer mechanical parts are used, which further reduces costs.<sup>28</sup> Another very relevant parameter in terms of repair costs is usually the price of spare parts.

Essential foundations for good reparability must be laid at the stage of design (see section 1). In addition to improvements in terms of modular design and the interchangeability of important battery components, **software aspects** are also becoming increasingly relevant, as electric vehicles are becoming more and more like electrical appliances whose reparability is often limited by software dependencies.<sup>29</sup> In this context, repair-unfriendly manufacturer practices such as part pairing or coding are also problematic. The latter are increasingly being used to control various parts and components in vehicles, which can hinder repairs.<sup>30</sup>

#### Necessary measures to promote repair

The EU Batteries Regulation has failed to establish a good basis for a strong repair infrastructure for EV batteries. A **right to repair** is needed that guarantees important legal requirements for repair. Without sufficient requirements, a situation similar to that of electrical appliances could arise,

where fully functional products have to be discarded prematurely at high environmental impacts because they cannot be repaired or the costs of repair are too high.

Binding ecodesign specifications for the reparability of EV batteries are an important basis for repair (see section 1). The **availability of spare parts** also plays a decisive role. Relevant criteria here are the guaranteed availability period from product purchase, the procurement channel, the delivery time and the price. The price of spare parts should be in appropriate proportion to the original battery price. DUH demands that spare parts for EV batteries must be available for 15 years after the battery purchase. In addition to spare parts, software applications should also be subject to these obligations and be made available for at least 15 years, ensuring safe use without restricting functionality.

Repairs should not only be feasible for manufacturers, but also for (certified) **independent repair workshops** in order to establish a manufacturer-independent repair infrastructure and thus promote **low repair costs**. Therefore, these independent players should be provided with non-discriminatory access to spare parts, software updates, tools as well as repair and dismantling instructions. Anti-repair practices from manufacturers such as part pairing must be banned, as independent repairers often lack access to the necessary codes or pairings.<sup>31</sup> In addition, EV battery repairs should be tax-privileged to favor repair over battery replacement further.

#### 4. Successful battery passport and strong consumer information

From 2027, the **EU Batteries Regulation** will require every EV battery placed on the market in the

EU to have a battery passport (Article 77). The battery passport is intended to enable various stakeholders to obtain relevant information about the battery. For example, in future consumers will be able to get information on the material composition or the CO<sub>2</sub> footprint. The introduction of the battery passport is an important step towards promoting repair, reuse and recycling and making it easier for consumers to make ecological purchasing decisions. However, it is now important that maximum transparency is achieved for consumers, repair, reuse and recycling companies in the subsequent detailed regulation.

The data stored in the battery passport is particularly relevant for **repairs** and in the case when passing on the EV battery for **reuse**. Thus it promotes the service life and safety of batteries during use. The data required for repair and reuse is described in detail in sections 2 and 3. For **consumers**, it is crucial that the information on the battery is easily accessible at the time of purchase and via product labeling, and that information on the origin and type of raw materials, recycled content, CO<sub>2</sub> footprint, pollutant content, expected service life and reparability is included in the battery passport. Reparability could be assessed using a repair



Battery passport: Important instrument for more transparency

index/label similar to the ecodesign regulations for smartphones and tablets.

In addition, the battery passport offers enormous potential for obtaining more information about the **life cycle of specific batteries**. For example, data on the manufacturer and distributor as well as maintenance work, repairs (including defects) and resales should be stored in the battery passport. At the end of their life, the battery passport could also be used to ensure proper disposal, for example by requiring owners of EV batteries to provide a disposal certificate officially. The battery passport also requires good **networking with other product passports**, e.g. with the planned product passport for vehicles. Corresponding interfaces or information on networked product passports should therefore also be noted in the battery passport.

## 5. Extended product responsibility and reliable collection

According to the **EU Batteries Regulation** (Article 61), manufacturers and producer systems of EV batteries must take back waste EV batteries free of charge from August 2025 and ensure that they are collected separately and sent for reuse or recycling. Additionally, dealers will be obliged to accept EV batteries at the point of sale and hand them over to the manufacturers from that date (Article 62).

DUH very much welcomes the important basis of the EU Batteries Regulation for a **system of extended product responsibility (EPR)** for EV batteries laid down by the EU Batteries Regulation. However, beyond setting obligations for collection and recycling, a comprehensive framework for EPR is needed to minimize environmental impacts from production to disposal of EV batteries. An EPR system should also oblige manufacturers to promote

repair and reuse in line with the waste hierarchy, for example through binding reuse targets and mandatory tests for the reusability of end-of-life EV batteries. In addition, manufacturers should take more responsibility for raising consumer awareness of environmentally friendly behavior.

DUH supports the "producer-driven model" and "competitive PROs" models for EPR developed and favored as part of a study on textiles. The models described enable more binding targets to be met (e.g. with regard to collection, recycling and reuse) and simpler enforcement.<sup>32</sup> DUH welcomes the option provided in the EU Batteries Regulation for member states to make the fulfillment of product responsibility through **collective systems** mandatory. The formation of collective systems for the implementation of producer responsibility should be mandatory throughout the EU, as this can considerably facilitate enforcement within the framework of product responsibility and thus contribute to better fulfillment of producer obligations.<sup>32</sup> Collective systems can also be used to integrate eco-modulation mechanisms more easily (see section 1).

**Reliable collection** is also the basic prerequisite for proper reuse or recycling of EV batteries. In contrast to portable batteries, these batteries are not disposed of via domestic waste collection in the event of incorrect disposal, but rather through illegal resale inland and abroad, where proper end-of-life recycling is no longer guaranteed. Incentives are therefore also needed for consumers, workshops and insurance companies to dispose of EV batteries properly. In this context, DUH considers a deposit system or an obligation to provide certificate of disposal to be suitable instruments. In addition, a system is needed that enables better traceability of EV batteries. This could be based on the battery passport, for example (see section 4).



In China, a platform supporting the secure collection of EV batteries was already established in 2018.<sup>33</sup>

To restrict **illegal exports** of EV batteries, a clearer classification of end-of-life batteries as hazardous waste is needed, as well as clearer responsibilities if batteries become waste.<sup>34</sup> Illegal exports often involve entire vehicles. According to current estimates, between 3.4 and 4.7 million end-of-life vehicles are illegally exported from the EU to Africa every year, in addition to 1.8 million confirmed exports.<sup>35</sup> The VDEoL draft (13.07.2023) contains valuable approaches to curb the illegal export of EV batteries through better definitions (e.g. on roadworthiness). However, these measures must be complemented by effective official and customs controls as well as sanctions in order to be successful.

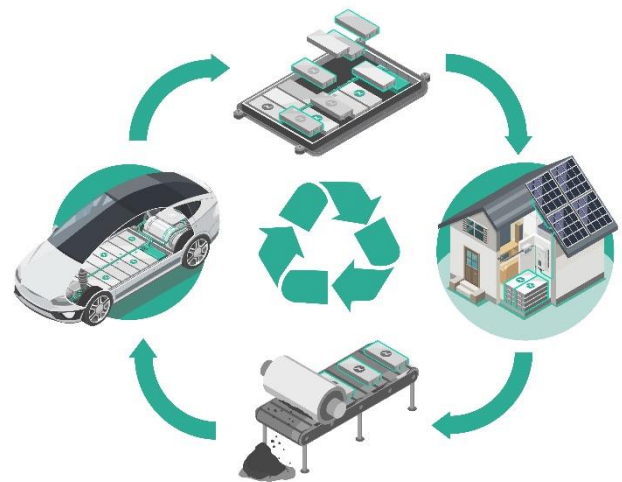
However, the **export of roadworthy vehicles** outside the EU remains legal. In these cases, DUH is calling for the EPR fees that manufacturers save by exports to be made available to the receiving countries for the operation of waste management systems. Producer responsibility should only end when the vehicle or battery has been demonstrably recycled to a high standard. It is also necessary to only allow these exports to countries that can demonstrate similar environmental standards for recycling as in the EU. The VDEoL should also stipulate that relevant information, e.g. on state of health of the battery, must be passed on to receiving countries when used EV batteries are exported.

## 6. High-quality recycling

Currently, EV batteries are usually made from primary raw materials, the extraction of which is associated with significant environmental impacts. Forecasts show that the demand for key materials for the electrification of passenger transportation

in the EU will increase significantly by 2050.<sup>36</sup> In addition to the promotion of reuse measures, this material demand could also be significantly reduced through the efficient recycling of batteries at the end of their life.<sup>9</sup> Strong recycling structures would thus significantly reduce the environmental impact of battery production and promote a regional supply of raw materials.

A basic prerequisite for efficient recycling structures in Europe are **high-quality collection structures** (see section 5). It is also important that recyclable materials are not exported for inferior recycling (e.g. through illegal exports of end-of-life vehicles). In this context, DUH recommends classifying the "black mass" generated during recycling as



Following a second life, high-quality recycling can make an important contribution to reducing the demand for resources

hazardous waste in order to prevent exports to countries with poor environmental standards. Currently, the lack of treatment capacities in the EU means that a large proportion of the black mass generated in Europe is exported to Asia.<sup>37</sup>

A strong recycling market is needed in Europe in order to optimally recover the recyclable materials contained in batteries after the longest possible period of use and to meet the recycling efficiency

and recovery targets set out in the EU Batteries Regulation (Article 71). The **CRMA** sets targets for recycling capacity in the EU for the first time: At least 25 percent of the annual consumption of strategic raw materials should be recycled by 2030. DUH calls for such targets to be set not only for the member states but also for specific players (e.g. producers) in order to achieve greater commitment.

A recycling-friendly design also plays an important role (see section 1). Relevant **information for recyclers**, e.g. on dismantling or the raw materials contained, should be provided in the battery passport and on the battery labels. The **quality of the recycling** is also relevant: only if batteries are recycled to "battery-grade" quality, the recovered materials can be used for the production of new EV batteries. Legal requirements must therefore absolutely prevent the downcycling of battery materials (e.g. for use in road construction).

DUH welcomes the fact that **material-specific recycling targets** for lithium, cobalt, nickel, copper and lead have been set for the first time in the EU Batteries Regulation. This instrument promotes the recycling of currently less profitable materials (e.g. lithium and cobalt) and supports the further development of recycling processes.

However, in order to close material cycles, it is also essential to promote the use of secondary materials in production. Political instruments should ensure that **secondary raw materials** become competitive with primary raw materials. This requires further measures, such as a primary resource tax or tax concessions for secondary raw materials.

**Recycled content targets** are an important instrument for promoting the timely establishment of high-quality recycling structures. The EU Batteries Regulation sets out corresponding requirements

for the production of EV batteries with regard to lithium, cobalt, lead and nickel and is an important signal for the recycling industry. However, the design of the legal details is crucial to the success of the political instrument of recycled content targets. Under no circumstances should the targets be met solely through recycled content from production waste (PIR, post-industrial recycled content), which may even be imported from abroad. Usually, there are already sufficient economic incentives for the recycling of production waste, so that political measures should focus on promoting more complex recycling processes for batteries from the use phase (PCR, post-consumer recycled content). Only PCR should therefore be recognized for meeting the targets of the EU Batteries Regulation. This would also create incentives to make more efficient use of the resource potential of LIBs from waste electrical and electronic equipment and portable batteries.

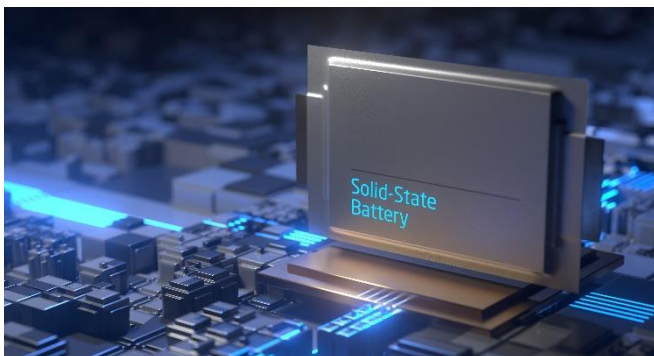
## 7. Promotion of research and development

Technological progress and research into alternative battery cell technologies are also expected to help reduce the need for critical raw materials such as lithium or cobalt in the future. Currently, there is considerable potential to improve the resource efficiency of EV batteries through various technological developments.

The **lithium-ion battery** is the cell technology currently dominating the market. It is characterized by a high energy and power density and is therefore particularly suitable for mobile applications.<sup>38</sup> The advantages of LIBs are that they can be charged quickly and have a good durability, although the latter depends heavily on storage and usage behavior.<sup>11,39</sup> Additionally, LIBs can cause

fires if used, stored, transported or disposed of improperly.

According to forecasts, the production of **NMC** (nickel-manganese-cobalt) and **LFP** (lithium-iron-phosphate) battery cells, both of which belong to the LIB battery cell technology, will dominate in Europe by 2030.<sup>40</sup> LFP batteries are more durable than classic LIBs, do not require critical metals such as cobalt, nickel or manganese and are more cost-effective (per KWh).<sup>41,42</sup> Iron and phosphate are good available resources and easy to recycle.<sup>43,44</sup> However, LFP batteries have a lower energy density than LIBs and therefore require more battery cells and space. They are therefore primarily used for stationary energy storage or are suitable for smaller vehicles such as motorized two-wheelers or small cars. In Europe, NMC batteries are currently mainly used for electric vehicles with long ranges and high outputs. LFP batteries are also less



New battery cell technologies such as the solid-state battery can significantly reduce the need for critical raw materials for battery production

flammable than NMC batteries and therefore safer.<sup>40</sup> In Asia, the demand for LFP batteries already exceeds that for NMC batteries, as the advantages were recognized early on.<sup>45,46</sup> The potential of LFP technology for resource conservation should also be increasingly exploited in Europe.

One LIB technology that has not yet been commercialized is the **solid-state battery**. Technical advantages include high energy density, safety, short charging times and longer ranges compared to classic LIBs. Solid-state batteries also offer clear advantages from an environmental point of view due to their durability, more compact and lighter construction and the avoidance of cobalt, among other things.<sup>47,48</sup> They are already being used in local public transport.<sup>49</sup>

Research is also focusing on an alternative cathode material for batteries in order to avoid the need for critical lithium. **Sodium-ion batteries (SIBs)** are particularly promising here and are on the verge of commercialization.<sup>36</sup> Sodium is widely available on earth and is not critical in terms of extraction, which gives SIBs clear environmental advantages over LIBs. SIBs are also non-flammable and therefore safe even at high and low temperatures.<sup>36,50</sup> However, technical challenges currently still exist due to a lower energy density and a short service life compared to LIBs, which severely limits the range of applications.<sup>51,52</sup> Forecasts indicate that LFP and SIB technologies will expand in Europe by 2050, while the proportion of NMCs will decline.<sup>36</sup>

Europe should **promote** the development and **establishment of new battery technologies** that use fewer critical raw materials or have a lower environmental impact (e.g. SIBs or solid-state batteries). Furthermore, innovations to improve the durability, reparability and recyclability of the battery are necessary. A one-sided focus of the EU market on one battery cell technology (e.g. NMC batteries) should be avoided. New battery cell technologies should also initially coexist so that operating battery types do not have to be retired prematurely.



## 8. Adaptations in mobility behavior

If current trends in mobility behavior continue, 2.9 million tons of lithium (Mt), 10.7 Mt of nickel, 0.8 Mt of cobalt and 5.5 Mt of manganese will be required in Europe in 2050 with the currently prevailing battery cell technologies.<sup>36</sup> The potential to reduce resource requirements in the battery sector through adapted mobility must therefore be exploited under any circumstances. Measures here may on the one hand relate to a reduction in the number of passenger cars and on the other hand to individual vehicle characteristics (e.g. weight, size, battery capacity).

A shift from combustion engines to electric drives is necessary for both climate protection and overall ecological reasons.<sup>1</sup> However, this does not mean that every car currently registered should be replaced by an electric car. DUH is calling for **the total number of passenger cars to be halved in the long term** as part of a fundamental change in mobility. To achieve this, walking, cycling and local public transport must be significantly promoted and made more attractive, facilitating the reduced use of private vehicles. The Federal Environment Agency of Germany recommends a target motorization level of maximum 150 passenger cars per 1,000 inhabitants, while Germany currently has



Reducing the total number of cars as part of a fundamental change in mobility also helps to protect resources

over 570 cars/1,000 inhabitants.<sup>53,54</sup> Political instruments to promote a mobility transition include, e.g. adjustments of taxes and parking fees for particularly large and heavy vehicles, a reduction in public transport, a mileage-based toll and the abolition of counterproductive subsidies such as the diesel privilege or company car tax in Germany.

Electric cars can only fully exploit their ecological advantages over combustion engines if they are as small and light as possible. **Reducing the weight or size of vehicles and batteries** is therefore another important lever for more resource conservation in the passenger car segment. According to an analysis of new vehicle registrations in Germany from January to November 2023 compared to the previous year, almost half (46%) of all electric vehicle models in Germany are sports utility vehicles (SUVs), while the proportion of lighter vehicle classes is falling for years.<sup>55</sup> The current focus of the German passenger car market on models such as SUVs or off-road vehicles is highly problematic from a resource perspective, as they require batteries of above-average size. So far, there are insufficient political measures to reverse this trend. Possible instruments would be, for example, taxes or environmental zones that take vehicle weight into account. The German city of Tübingen charges higher parking fees for heavy vehicles, showing another possible instrument.<sup>56</sup> Beyond that, there is currently a lack of ecodesign specifications aimed at reducing vehicle weight overall (see section 1).

## 9. Binding resource reduction targets

In order to achieve greater commitment in the area of resource protection, DUH calls for the political anchoring of resource protection targets at EU level and in the member states (e.g. a material footprint reduction target). Such a regulation

could be designed in the same way as climate legislation and set sub-targets for certain sectors - such as the mobility sector. Austria has already set corresponding resource protection targets in law.

A resource conservation target in the transport sector would have the advantage that the most effective measures - presumably at the upper end of the waste hierarchy - would make the greatest contribution to achieving the target and would therefore be prioritized. However, it is important that the targets are also **made binding**. For example, the targets could become binding for producers, who could then choose to take measures to improve resource efficiency (e.g. a reduction in vehicle weight).

However, resource protection targets should not relate exclusively to the critical raw materials required for a drive transition in order to avoid creating barriers to the shift to electromobility. In order to achieve greater resource efficiency in the field of critical raw materials, political **targets** could be set **for sustainable consumption** in certain areas (e.g. with regard to the calculated per capita consumption for vehicles or electrical appliances).

## 10. Reliable enforcement

Regulations for EV batteries can only be effective in protecting the environment and human health if they are effectively implemented and monitored. Therefore, enforcement authorities must be provided with **sufficient resources** to enable them to carry out their own measurements, plausibility checks and unannounced inspections. DUH also recommends that enforcement and monitoring tasks may be established across the EU in some overarching areas in order to pool expertise, network stakeholders and **harmonize enforcement practices in the EU**.

Currently, there are already considerable **enforcement deficits** in the area of batteries, particularly with regard to illegal exports or the full inclusion of manufacturers in EPR systems. There is also partially a lack of effective sanction mechanisms, e.g. certain violations are not classified as administrative offenses in German battery law. Especially well performing economic players highly depend on successful enforcement, as otherwise they will be forced out of the market by companies with lower environmental standards.

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- <sup>1</sup> Deutsche Umwelthilfe (2024). 10 facts on the environmental compatibility of electric vehicles - How electromobility is becoming the can contribute to environmental protection and resource [conservation](https://www.duh.de/fileadmin/user_upload/download/Projektinformation/Kreislaufwirtschaft/Batterien/240130_Umweltvertraeglichkeit_Elektrofahrzeuge_FINAL.pdf); [https://www.duh.de/fileadmin/user\\_upload/download/Projektinformation/Kreislaufwirtschaft/Batterien/240130\\_Umweltvertraeglichkeit\\_Elektrofahrzeuge\\_FINAL.pdf](https://www.duh.de/fileadmin/user_upload/download/Projektinformation/Kreislaufwirtschaft/Batterien/240130_Umweltvertraeglichkeit_Elektrofahrzeuge_FINAL.pdf)
- <sup>2</sup> Note: For reasons of simplification, we use the term "reuse" for both preparation for reuse and reuse prior to achieving waste status. Legally, however, these terms should be treated separately.
- <sup>3</sup> Deutsche Umwelthilfe (2023, July 14). *Deutsche Umwelthilfe and Transport & Environment on the EU Batteries Regulation* EU Batteries Regulation: New requirements for recycling and CO2 limitation important progress, pent-up demand for reuse and repair. <https://www.duh.de/presse/pressemitteilungen/pressemitteilung/deutsche-umwelthilfe-und-transport-environment-zur-eu-batterieverordnung-neue-vorgaben-zu-recycli/>
- <sup>4</sup> ECOS, DUH, RREUSE (2023). How to reduce our dependency on critical raw materials by stimulating circularity. ECOS, DUH and RREUSE position on the Critical Raw Materials Regulation proposal
- <sup>5</sup> Repair Round Table (2023, March 22). *No right to repair: The EU Commission's proposal ignores the real problems and will not make repairs cheaper and more accessible*
- <sup>6</sup> Peters, J. F., Baumann, M., Zimmermann, B., Braun, J., & Weil, M. (2017). The environmental impact of Li-Ion batteries and the role of key parameters - A review. *Renewable and Sustainable Energy Reviews*, Volume 67, Pages 491-506. <https://doi.org/10.1016/j.rser.2016.08.039>.
- <sup>7</sup> Ökopol GmbH (2023). Field of action: vehicles and batteries. Input from the project "Scientific support and monitoring of the National Circular Economy Strategy NKWS"
- <sup>8</sup> United Nations Environment Programme, & International Resource Panel (2011). *Recycling Rates of Metals: A Status Report*. <https://wedocs.unep.org/20.500.11822/8702> UNEP (2011) *Recycling Rates of Metals: A Status Report*.
- <sup>9</sup> Neef, C., Schmaltz, T., & Thielmann, A. (2021). Recycling of lithium-ion batteries: Opportunities and challenges for mechanical and plant engineering. Fraunhofer Institute for Systems and Innovation Research ISI. DOI [10.24406/publica-fhg-301299](https://doi.org/10.24406/publica-fhg-301299)
- <sup>10</sup> Koyuncu, B., Hoffmann, M., Rateau, F., & Vahk, J. (2021). Chemical recycling and recovery. ECOS, German Environmental Aid, Zero Waste Europe. <https://zerowasteurope.eu/library/chemical-recycling-and-recovery-recommendation-to-categorise-thermal-decomposition-of-plastic-waste-to-molecular-level-feedstock-as-chemical-recovery/>
- <sup>11</sup> Thielmann, A., Sauer A., & Wietschel, M. (2015). Overall roadmap for lithium-ion batteries 2030. Fraunhofer Institute for Systems and Innovation Research ISI. <https://publica.fraunhofer.de/entities/publication/a1cc3155-22da-4018-9de9-cc65b2ae4e53/details>
- <sup>12</sup> Mangler, A., Hofmann, R. (12.07.2018). Li-ion batteries: How can thermal runaway be prevented? <https://www.el-elektronikpraxis.de/li-ion-akkus-wie-laesst-sich-ein-thermal-runaway-verhindern-a-c21f0f91c05b06cd44e83bad867daae7/>
- <sup>13</sup> Koehler, R. A., Baron, Y., Bulach, W., & Heinemann, C. (2018). *Ecological and economic assessment of resource consumption - Stationary energy storage systems in industrial production*
- <sup>14</sup> Rallo, H., Benveniste, G., Gestoso, I., & Amante, B. (2020). Economic analysis of the disassembling activities to the reuse of electric vehicles Li-ion batteries. *Resources, Conservation and Recycling*, 159, 104785. <https://doi.org/10.1016/j.rescon-rec.2020.104785>
- <sup>15</sup> Tankou, A., Bieker, G., & Hall, D. (2023). *Scaling up reuse and recycling of electric EV batteries: Assessing challenges and policy approaches*. International Council on Clean Transportation (ICCT) White Paper
- <sup>16</sup> Fischhaber, S., Reget, A., Schuster, S. F., & Hesse, H. (2016). *Study: Second-life concepts for lithium-ion batteries from electric vehicles*. Research Center for Energy Economics (FfE) e. V.
- <sup>17</sup> Mathieu, L. & Mattea, C. (2021). From dirty oil to clean batteries. *Transport & Environment*
- <sup>18</sup> Bobba, S., Mathieux, F., Ardente, F., Blengini, G. A., Cusenza, M. A., Podias, A., & Pfrang, A. (2018). Life Cycle Assessment of repurposed electric EV batteries: an adapted method based on modeling energy flows. *Journal of Energy Storage*, 19, 213-225. DOI: [10.1016/j.est.2018.07.008](https://doi.org/10.1016/j.est.2018.07.008)
- <sup>19</sup> Wewer, A., Bilge, P., & Dietrich, F. (2021). *Advances of 2nd life applications for lithium ion batteries from electric vehicles based on energy demand*. *Sustainability* (2021), 13(10). <https://doi.org/10.3390/su13105726>
- <sup>20</sup> Schoenfish, M. & Dasgupta, A. (2024, January 17). *Grid-scale storage*. IEA. <https://www.iea.org/energy-system/electricity/grid-scale-storage#tracking>
- <sup>21</sup> Abdelbaky, M., Peeters, J. R., Duflou, J. R., & Dewulf, W. (2020). Forecasting the EU recycling potential for batteries from electric vehicles. *Procedia CIRP*, Volume 90, 432-436. <https://doi.org/10.1016/j.procir.2020.01.109>



- <sup>22</sup> Autocirc (2024, January 20). Collaboration: <https://autocirc.com/collaboration/>
- <sup>23</sup> Breiter, A., Linder, M., Schuldt, T., Siccardo, G., & Vekić, N. (2023, March 13). *Battery recycling takes the driver's seat*. <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-recycling-takes-the-drivers-seat>
- <sup>24</sup> Kotak, Y. et al. (2021). End of Electric EV batteries: Reuse vs. Recycle. <https://doi.org/10.3390/en14082217>
- <sup>25</sup> Vorholt, F., Bünting, A., Bechberger, M. (2023). *Turbulent battery cell market*. VDI/VDE Innovation + Technology GmbH
- <sup>26</sup> Thatcham Research (2023). *Impact of BEV Adoption on the Repair and Insurance Sectors*
- <sup>27</sup> General Association of Insurers (2023). *Study: e-cars are a third more expensive to repair than comparable combustion cars*. <https://www.gdv.de/gdv/medien/medieninformationen/studie-e-autos-sind-bei-der-reparatur-ein-drittel-teurer-als-vergleichbare-verbrenner-155216>
- <sup>28</sup> Veza, I., Asy'ari, M., Idris, M., Epin, V., Rizwanul Fattah, I. M., & Spraggon, M. (2023). Electric vehicle (EV) and driving towards sustainability: Comparison between EV, HEV, PHEV, and ICE vehicles to achieve net zero emissions by 2050 from EV. *Alexandria Engineering Journal, Volume 82*. DOI:[10.1016/j.aej.2023.10.020](https://doi.org/10.1016/j.aej.2023.10.020)
- <sup>29</sup> Edwards, J. (2022, December 1). *Could Software Issues Delay Widespread Electric Vehicle Adoption?* Information Week. <https://www.informationweek.com/software-services/could-software-issues-delay-widespread-electric-vehicle-adoption->
- <sup>30</sup> Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on circularity requirements for vehicle design and on the management of end-of-life vehicles, amending Regulations (EU) 2018/858 and 2019/1020 and repealing Directives 2000/53/EC and 2005/64/EC
- <sup>31</sup> See Box 4 Part Pairing, EEB (2023). ICT: a top horizontal priority in sustainable product policy
- <sup>32</sup> Federal Environment Agency (2023). *Development of possible models for extended producer responsibility for textiles Product responsibility models for textiles* (ProTex)
- <sup>33</sup> Reuters. (2018, July 25). *China launches pilot EV battery recycling schemes*. <https://www.reuters.com/article/us-china-autos-batteries/china-launches-pilot-ev-battery-recycling-schemesidUSKBN1KF375>
- <sup>34</sup> Yeo, R. (2023, July 6). European EU Batteries Regulations to restrict black mass exports to secure raw materials; <https://www.fastmarkets.com/insights/european-battery-regulations-to-restrict-black-mass-exports/>
- <sup>35</sup> Kitazume, C., Kohlmeyer, R., & Oehme, I. (2020). *Effectively tackling the issue of millions of vehicles with unknown whereabouts*. Federal Environment Agency
- <sup>36</sup> Transport & Environment. (2023). *Clean and lean: Battery metals demand from electrifying passenger transport*. <https://www.transportenvironment.org/discover/clean-and-lean-battery-metals-demand-from-electrifying-cars-vans-and-buses/>
- <sup>37</sup> EU Recycling Magazine (2021). By no means dark magic: black mass. *EU Recycling Magazine*, 11/2021, 40. <https://eu-recycling.com/Archive/33421>
- <sup>38</sup> Fraunhofer Institute for Systems and Innovation Research ISI (2023). *Alternative Battery Technologies Roadmap 2030+*. doi: 10.24406/publica-1342
- <sup>39</sup> Ma, S., Jiang, M., Tao, P., Song, C., Wu, J., Wang, J., Deng, T., & Shang, W. (2018). Temperature effect and thermal impact in lithium-ion batteries: A review. *Progress in Natural Science: Materials International, Volume 28, (6)*, 653-666. <https://doi.org/10.1016/j.pnsc.2018.11.002>
- <sup>40</sup> Fraunhofer ISI. (2023, June 12). *Global battery production: Analysis of locations and quantities of cells with LFP and NMC/NCA cathodes*. Fraunhofer Institute for Systems and Innovation Research ISI. <https://www.isi.fraunhofer.de/de/blog/themen/batterie-update/globale-batterieproduktion-analyse-standorte-mengen-zellen-lfp-nmc-nca-kathoden.html>
- <sup>41</sup> Schütte, P. (2021). Cobalt. Information on sustainability. Federal Institute for Geosciences and Natural Resources. DOI: 10.25928/68sf-8567
- <sup>42</sup> WWF (2019, May 29). *Mining: The consequences of global resource extraction*. <https://www.wwf.de/themen-projekte/waelder/mining>
- <sup>43</sup> EnBW (2023, October 10). *LFP batteries for electric cars: advantages and disadvantages at a glance*. <https://www.enbw.com/blog/elektromobilitaet/laden/lfp-akkus-fuer-e-autos-vor-und-nachteile-im-ueberblick/>
- <sup>44</sup> Kumar, J., Neiber, R. R., Park, J., Soomro, R. A., Greene, G. W., Mazari, S. A., Seo, H. Y., Lee, J. H., Shon, M., Chang, D. W., Cho, K. Y. (2022). Recent progress in sustainable recycling of LiFePO<sub>4</sub>-type lithium-ion batteries: Strategies for highly selective lithium recovery. *Chemical Engineering Journal, Volume 431 (Part 1)*. <https://doi.org/10.1016/j.cej.2021.133993>
- <sup>45</sup> Fastmarkets (2023, July 19). LFP batteries extend dominance over NCM batteries in China: <https://www.fastmarkets.com/insights/lfp-batteries-extend-dominance-over-nmc-batteries-china/>
- <sup>46</sup> Burow, D. (2021, April 26). *LFP: Advantage for China in the battery market*. Table Media. <https://table.media/china/standpunkt/lfp-vorteil-fuer-china-batteriemarkt/>
- <sup>47</sup> Kartini, E., & Genardy, C. T. (2020). The Future of All Solid State Battery. IOP Conference Series. Materials Science and Engineering, 924 012038. DOI 10.1088/1757-899X/924/1/012038

- 
- <sup>48</sup> Vattenfall (2023, March 24). *New battery technologies: Does the future belong to the solid-state battery?* <https://www.vattenfall.de/infowelt-energie/e-mobility/emobility-feststoffbatterie>
- <sup>49</sup> Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM (2023). *Solid-state batteries for electromobility*. <https://www.ifam.fraunhofer.de/de/magazin/festkoerperbatterien-fuer-die-elektromobilitaet.html>
- <sup>50</sup> Manthey, E. (2023, December 14). *Can sodium-ion batteries replace lithium-ion ones?* ING. <https://think.ing.com/articles/can-sodium-ion-batteries-replace-lithium-ion-batteries/>
- <sup>51</sup> Jendrischik, M. (2023, March 19). *Sodium battery: advantages and disadvantages compared to lithium-ion batteries*. Cleanthinking.de. <https://www.cleanthinking.de/natrium-batterie-vorteile-und-nachteile/>
- <sup>52</sup> Bai, H., & Song, Z. (2023). Lithium-ion battery, sodium-ion battery, or redox-flow battery: A comprehensive comparison in renewable energy systems. *Journal of Power Sources*, 580. <https://doi.org/10.1016/j.jpowsour.2023.233426>
- <sup>53</sup> Federal Environment Agency (2022, September 26) *The city for tomorrow: The vision*. <https://www.umweltbundesamt.de/themen/verkehr/nachhaltige-mobilitaet/die-stadt-fuer-morgen-die-vision>
- <sup>54</sup> Federal Statistical Office (DESTATIS). (2022, September 15) *Car density at record high in 2021*
- <sup>55</sup> Center of Automotive Management (2023, December 12). *Development trends in electromobility: Segment and model analysis of new registrations in Germany (Jan-Nov 2023)*. <https://auto-institut.de/automotiveinnovations/emobility/entwicklungs-trends-der-elektromobilitaet-segment-und-modellanalyse-der-neuzulassungen-in-deutschland-jan-nov-2023/>
- <sup>56</sup> Stieber, B. (2021, September 21). *SUV parking is getting expensive*. TAZ. <https://taz.de/Tuebingen-will-weg-von-der-Auto-stadt/!5798007/>