LEVERAGING THE EU BATTERY PRODUCTION TO ACHIEVE NET-ZERO WITH LIGHT ELECTRIC VEHICLES

POSITIONING PAPER

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EIT Urban Mobility

EIT KIC Urban Mobility S.L. Torre Glories,
Diagonal 211 08018 Barcelona
Spain

eiturbanmobility.eu

EIT InnoEnergy

Kennispoort 6th floor
John F. Kennedylaan 2
5612 AB Eindhoven
The Netherlands

innoenergy.com

Contact

Yoann Le Petit
Thought Leadership Manager
EIT Urban Mobility
yoann.lepetit@eiturbanmobility.eu

Hernan Pajaro
Innovation Manager Mobility
EIT InnoEnergy
hernan.pajaro@innoenergy.com

Jennifer Dungs
Global Head of Mobility
EIT InnoEnergy
Jennifer.dungs@innoenergy.com

eit Urban Mobility

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Contents

List of Acronyms

BMS	Battery Management System
EU	European Union
eVTOL	Electric vertical take-off and landing
GDP	Gross Domestic Product
ICE	Internal Combustion Engine
LEV	Light Electric Vehicle
LFP	Lithium Iron Phosphate
LMFP	Lithium Manganese Iron Phosphate
LMO	Lithium Manganese Oxide
LMT	Light Means of Transport
LNMO	Nithium Manganese Nickel Oxide
NCA	Lithium Nickel Cobalt Aluminium Oxide
NMC	Lithium Nickel Manganese Cobalt Oxide
NMCA	Nickel Manganese Cobalt Aluminium Oxide
OEM	Original Equipment Manufacturer
SoH	State of Health

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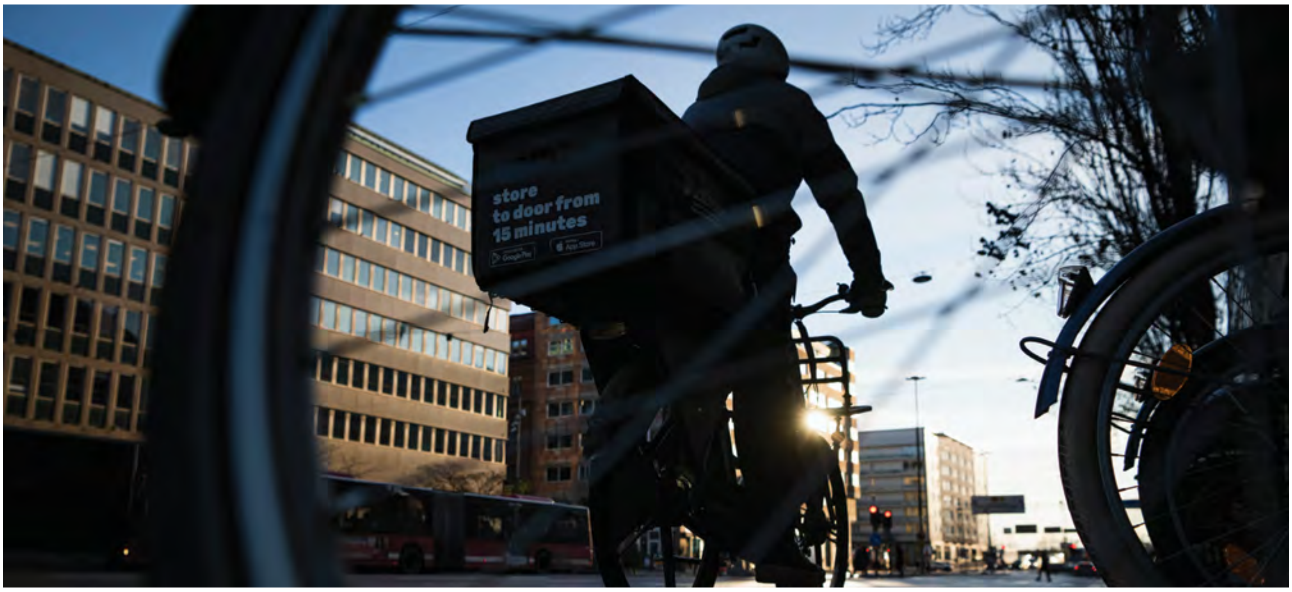

Executive Summary

Batteries have been at the heart of Europe's efforts to effectively decarbonise road transport and meet its climate goals [1]. Significant progress has been made in establishing a domestic battery value chain, with €126 billion in investments across 111 major projects [2], while stimulating enough initial demand for electric vehicles to cross the 5% inflexion point to trigger mass adoption [3, 4].

Despite this progress, existing policies are falling short of meeting the EU's 2030 targets [5], leaving a significant emissions gap of at least 165 $MtCO_2eq$ [6]. Furthermore, they are not generating enough electric vehicle demand to match the planned battery production in the mid-term, potentially leading to up to 3 times overcapacity until 2030 [7]. Nearly halfway through this decade, the EU must explore additional levers to accelerate the transition to sustainable mobility and bridge its emissions gap.

However, batteries are just a means to an end. For road transport, the end is to ensure the safe, sustainable, and affordable movement of people and goods. This requires a comprehensive view of the EU's mobility transition to equally support the uptake of alternative, fast-growing e-mobility solutions while strengthening their industrial and battery value chains. This approach will allow for strategically allocating valuable and limited resources and a more coordinated effort to achieve net-zero road transport.

Light Electric Vehicles (LEVs), such as e-bikes, e-kickscooters, e-mopeds, and e-motorcycles, are one such fast-growing solutions. With an estimated more than 10 million units sold in 2022 in Europe [8], LEVs are rapidly integrating in today's urban mobility. **LEVs have the potential to significantly reduce road transport emissions and help bridge the EU's 2030 emissions gap by addressing a substantial portion of urban mobility needs with less energy and CO_2 footprint** [9]

– saving at least 30 $MtCO_2eq$ just by replacing 13% of the daily short-distance trips made by cars and vans in cities [10]. Beyond environmental goals, this shift could also contribute to industrial and economic goals, creating 1 million green jobs in an industry that is expanding its European footprint [10].

In light of the EU's Net Zero Industry Act, which aims to bolster domestic production of clean technologies [11], the next critical question is **how to sustain and accelerate LEV adoption by leveraging Europe's strategic industrial resources, particularly its battery value chain.**

This paper examines the implications of securing a European battery supply chain for the LEV industry, highlighting key challenges and opportunities for both LEV and battery players. It analyses the demand for LEV batteries in Europe and their impact on the supply of critical materials. It also explores essential factors for LEV adoption, such as battery costs, safety, performance, and carbon footprint, focusing on future battery chemistries and considerations for battery circularity. This paper was a collaborative effort between EIT Urban Mobility and EIT InnoEnergy and draws on expert insights from the LEV and battery industries.

Key takeaways

- **There is potential room for EU battery production to power the modal shift to LEVs, with minimal demand for critical resources:**
    - By 2030, Europe's planned battery production capacity of 1,144-1,800 GWh will far exceed the projected battery demand of 317-696 GWh from electric cars under current policies [7].
    - Some of this capacity could be allocated to support the modal shift to LEVs, which have an estimated annual battery demand of 36 GWh by 2030 and 71 GWh by 2040 – requiring 10-30 times fewer critical metals than electric cars.
    - However, LEV players may face challenges securing an EU battery supply due to the low demand compared to electric cars, exacerbating existing supply chain risks, as 95% of LEV batteries are currently sourced from Asia [12].
- **In turn, LEVs could bolster the EU battery value chain by serving as ideal off-takers of standard cross-application cylindrical cell production:**
    - Europe's cylindrical cell production capacity is expected to increase from 7.6 GWh in 2021 (10% share) to 100 GWh by 2030 [13].
    - As the preferred format for most LEV applications, EU battery players could secure up to 85 GWh cumulative battery demand until 2030 from domestically produced LEVs, stimulating the ramp-up of cylindrical cell production.
    - Leveraging cylindrical cells as a strategic, cross-application standard enables EU battery players to meet diverse industry demands beyond LEVs and e-mobility [13], strengthening and diversifying the European battery value chain.

- **Current and future battery technologies will play a critical role in making LEVs a more attractive and viable alternative mode of transport:**
  - While ongoing advancements in battery technologies for passenger cars will continue to trickle down to LEVs, dedicated research and funding are still needed to meet LEV's specific requirements and overcome adoption barriers.
  - Key battery factors –safety, costs, and performance– directly impact the affordability and consumer acceptance of LEVs and, thus, their adoption. These advancements and their implications for LEVs are explored later in the paper.
- **Strengthening the current regulatory framework and upskilling the workforce are critical to a more sustainable and circular value chain:**
  - To facilitate the repair, reuse, and recycling of LEV batteries, the battery passport needs to become more operational and aligned with the needs of the various value chain actors.
  - There needs to be clearer and stronger safety and liability warranties in place to enable battery repairs.
  - Upskilling the labour force and investing in appropriate training is critical to facilitate repair and recycling, as will battery pack design for disassembly and circularity.

1 Small Size, Big Impact: The Potential of LEVs to Contribute to Net-Zero Climate and Industry Objectives

Light Electric Vehicles (LEVs)[1] are becoming an essential part of modern urban mobility and a key driver for the uptake of both shared and owned micromobility in Europe [14, 8]. Since 2018, over 800,000 shared e-kickscooters, e-bikes, and e-mopeds have been deployed across 515 European cities [15, 16], making an average of 1.5 million daily trips and contributing to the sector's €3.1 billion in revenue in 2022 [17]. **However, shared micromobility is only a portion of the LEVs hitting the road today.**

LEVs are already outselling electric cars in Europe [2]**.** E-bike sales alone reached 5.5 million units in 2022 [18], more than double the 2 million electric cars registered that year [4]. This growth is driven by the increasing accessibility and affordability of e-bikes, leading to one in five European households now owning an e-bike [19]. Similarly, because of time and money savings[2], nearly 5 million Europeans commute daily by mopeds and motorcycles [20]. **The two-wheeler sector is also electrifying rapidly[3]**: One in three new mopeds registered is electric, accounting for about 32% of total registrations in the five biggest EU markets in 2023, while e-motorcycles have seen an average annual growth of 37% since 2019 [21].

At this rate, **LEV sales are expected to almost double passenger car sales by 2030**, putting nearly 25 million new LEVs on the roads [12, 22]. The sheer volume of LEVs could become a key lever for the EU to significantly reduce road transport emissions and help bridge the expected gap in reaching its climate targets (see box 1).

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[1] LEVs encompass a wide range of electrically powered vehicles designed primarily for short-distance urban mobility, characterised by efficiency, affordability, and low environmental impact [2]. In this paper, the term aligns with the concept of Light Means of Transport (LMT) adopted by the European Commission but also includes other vehicles in the L-category, such as e-motorcycles, which have larger batteries with over 25 kg.

[2] On average, travelling by moped or motorcycle takes about 30% less time than by car, and the commuting cost could be up to 62% lower than that of a car [20].

[3] Despite the recent slowdown, where e-mopeds and e-motorcycles saw new registrations fall by 29% and 20% in 2023 [21]

Bridging road transport's emissions gap: The decarbonisation potential of LEVs

According to Transport & Environment, current Fit-for-55 measures will fall short of meeting the EU's 40% transport emissions reduction target by 2030 vs. 2005 [5]. The slow turnover of the vehicle park, with vehicles lasting an average of 5-10 years, means that 65-70% of the cars, vans and trucks on the road won't be zero-emission by 2030, **leaving a gap of over 165 $MtCO_{2eq}$ to address** [6].

Closing the emissions gap will require further measures to directly curb emissions at the vehicle park level by shifting future mobility demand of people and goods to more climate-friendly and cost-efficient alternatives like LEVs. LEVs can meet a substantial portion of the kilometres travelled by cars, vans, and trucks, using 79% less energy[4] and emitting 88% less CO_{2eq} per km over their lifetime [9], primarily in urban areas where 23% of the total EU transport GHGs are emitted [23].

About 60% of all passenger car trips in Europe are under 8 km, and considering restrictions like age, weather, and consumer adoption, about half of these trips could potentially be replaced by smaller LEVs, such as e-scooters, e-bikes, and e-mopeds [24]. Based on the results of a previous report [10], **replacing just 13% of the possible kilometres travelled of these short urban trips in 100 EU cities could save around 30 $MtCO_{2eq}$ per year[5] - already 20% of the projected emissions gap.**

Increasing the adoption of LEVs by replacing short urban trips made by passenger cars **has the potential to create almost 1 million direct and indirect jobs in Europe** [10] – as a reference, the entire automotive sector provides around 13.8 million direct and indirect jobs [25]. Thus, **LEVs can contribute to the EU Net-Zero Industry Act's goal** to boost clean-tech production in Europe [11]**. And the economic footprint of the EU-made LEV industry is growing**.

Since 2015, **e-bike production and assembly in Europe has increased sixfold**, reaching 5.4 million units sold in 2022 [18]. That year, over 1000 SMEs across the entire European bicycle industry provided 180,000 green manufacturing jobs and invested €1-2 billion in R&D [18, 26]. In 2019, **about five in seven two-wheelers sold were manufactured in Europe**. The European two-wheeler industry, with world-renowned brands and over 40 manufacturing and R&D

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[4] Energy consumption ranging from 0.8-10 kWh/100km (~4 kWh/100km average) [9] compared to battery electric vehicles ranging from 13.9-32.2 kWh/100km (~18.8 kWh/100km average) [68]

[5] The theoretical top-end emissions reduction potential is even higher if larger LEVs, such as e-motorcycles and microcars, are considered. A recent study by DLR found that trips of up to 20 km account for 80% of all car trips in Germany, and that replacing half of them with LEVs could theoretically save 58 $MtCO_2eq$ in Germany alone [9].

facilities, generated €5.8 billion in GDP and employed 133,000 people in 2019 [20]. However, it is only recently that most OEMs have announced new electric models in their roadmaps, particularly battery-powered scooters, commuters, and mopeds in the lower 1-4 kW range (equivalent to 50-125 cc) catering for the urban segment [27, 28].

Despite the increasing production of LEVs in Europe, **over 95% of their batteries are sourced from Asia, mainly from China, Japan, and Korea** [12]. These batteries are a crucial component, making up 35-50% of the cost of an LEV [29, 30]. Such heavy reliance on overseas supply chains exposes the industry to potential disruptions, price spikes, and market imbalances [31]. EU leaders have already expressed growing concerns about the impact of Chinese battery dumping on the wider e-mobility industry and have called for de-risking of the battery value chain [32].

Onshoring the battery value chain has become an EU priority to secure its green transition objectives and enhance European open strategic autonomy [1]. Significant progress has been made thanks to €127 billion in investments for 111 major projects facilitated by the European Battery Alliance [2]. Beyond building resilience, onshoring the battery value chain could enhance its sustainability with greener European batteries that can be up to 62% less carbon intensive than those produced in China [33].

The same drive to establish a robust and green battery value chain in Europe should also encompass the fast-growing LEV industry, given its crucial role in achieving the EU's climate and industrial objectives.

2 Small-sized Batteries, large-scale Strategy: Leveraging EU Battery Production to Power the Growth of LEVs and Beyond

Despite China's dominance in global battery cell manufacturing, with 82% of the market in 2023 [34], Europe has been catching up thanks to its large domestic electric vehicle market, driven by EU vehicle CO_2 standards [33]. Today, almost all EU countries[6] have passed the 5% tipping point in new car sales, which is crucial for spurring mass adoption [3, 4].

However, with current policies, **the demand for lithium-ion batteries for electric cars and vans in the EU is projected to reach 317 GWh by 2030** and increase only to 696 GWh if more ambitious policies are implemented [35]. Moreover, **this battery demand won't be enough to match Europe's planned battery capacity of 1,144 to 1,800 GWh by 2030 - nearly three times higher**[7] [7]. Without further action, this will further exacerbate the risk of delays, scale-downs, or cancellation for over two-thirds of this planned capacity, as reported by T&E [36]. Some of this capacity could be allocated to secure an EU battery supply for the growing LEV industry.

Europe's annual demand for LEV batteries will reach 36.2 GWh by 2030 and 70.8 GWh by 2040, under the current market projection (see Box 2). Despite the high volume of LEVs, their battery demand is significantly lower than electric cars and vans due to their smaller size. **This poses a significant challenge to LEV players who would face difficulties in securing a European battery supply with such low demand, thereby increasing the risk of overreliance on well-established overseas supply chains**. However, there is still an opportunity for European battery manufacturers, especially those venturing into producing standard formats for cylindrical cells.

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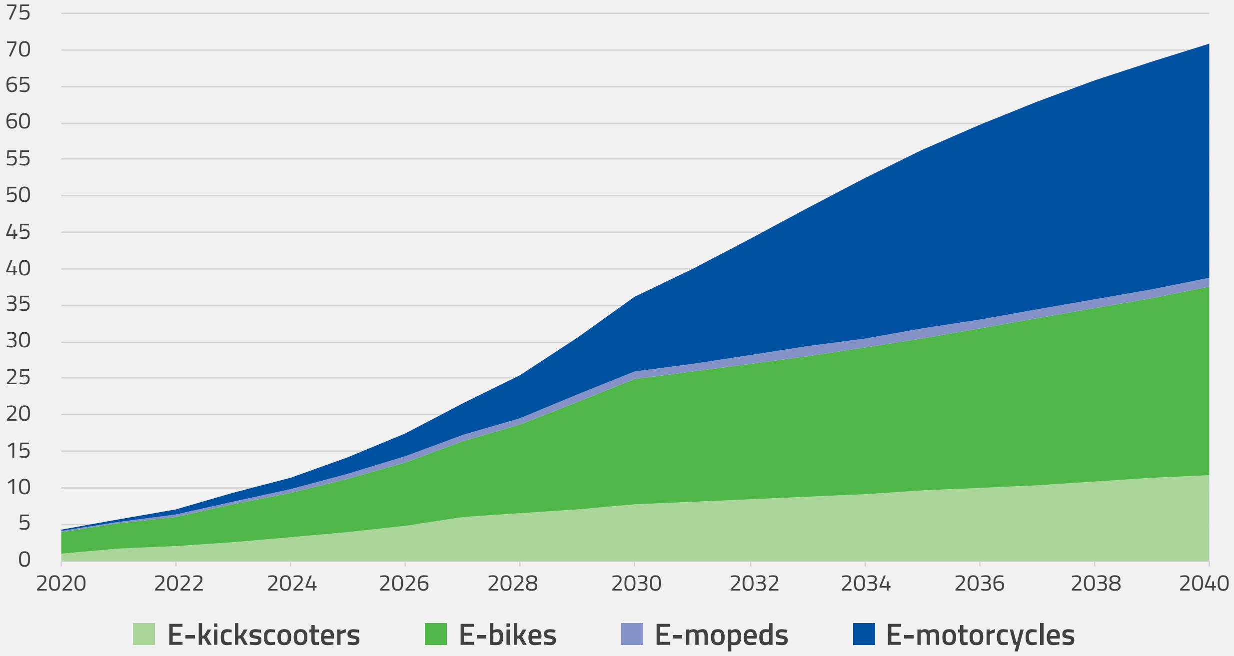
[6] According to the EEA, all but Cyprus, Poland, Czechia, and Slovakia had electric vehicle registrations lower than 5% [4].

[7] Even by including the battery demand from heavy-duty vehicles, energy storage, etc., for a total of 485-865 GWh, the overcapacity is still 2-3 times the demand.

Figure 1. Annual battery demand from LEVs in Europe (GWh/year)



Source: Based on data from BloombergNEF, McKinsey CFM, and own analysis.

Notes: E-kickscooters exclude e-monowheels, e-hoverboards, and other small personal LEVs. E-bikes include e-cargo bikes. E-mopeds include battery-power scooters and commuters. See Table 1 for baseline data on each LEV type's battery characteristics.

The expanding e-bike market and the rapid electrification of the two-wheeler segment will primarily drive the LEV battery demand. Current market projections estimate that over 23 million new LEVs will hit the roads by 2030:

E-bikes accounted for over 60% of both the estimated LEV battery units and tonnage placed on the market in 2020 [37, 38]. Sales forecasts predict over 12 million units in 2030 [39], creating an annual battery demand of 12.6 GWh (40% of the total), which will grow to 20.2 GWh in 2040 (31% of the total). The demand for **e-cargo bike** batteries could reach 3.2 GWh, with 1.3 million units sold by 2030, driven in part by their broader integration into delivery fleets for last-mile logistics [12]

By 2030, **electric two-wheeler** registrations are projected to reach 87% of the total for mopeds (up from 29% in 2022) and 60% for motorcycles (up from 4% in 2022) [22]. Despite making up only 1% of the estimated battery units placed on the market in 2020, two-wheelers represented 10% of the total tonnage. [37], due to the larger battery sizes of e-motorcycles (~20x larger). The annual battery demand for electric two-wheelers will reach almost 11.4 GWh in 2030 and 33.2 GWh in 2040 (36% and 51% of the total).

The fleet of **e-kickscooters** accounted for 26-28% of the estimated battery units and tonnage in 2020 [37], and is expected to grow, especially in the personal-use segment, with sales forecasts estimating about 10 million units by 2030 [12], creating an annual battery demand of 7.8 GWh in 2030, and increasing to 11.8 GWh in 2040.

Beyond 2030, battery demand across all LEV segments is expected to slow down as the e-bike and e-kickscooter markets mature, growing more in line with population and GDP growth, and the electrification rates of the two-wheeler segment align with net-zero targets.

Standard cylindrical 21700 cells (and its 18650 predecessors) are the most common form factors found in LEVs [40]. Compared to the alternative pouch and prismatic formats, cylindrical cells tend to be the most cost-effective due to established manufacturing processes, offering high flexibility, energy density, and robustness for compact and lightweight battery designs [13]. However, due to their small size and low energy content per cell, high-capacity battery packs, such as those for electric cars, require the complex integration of many individual cells [13]. Nonetheless, following Tesla's lead, several automotive OEMs have announced the use of cylindrical cells for selected models, especially larger formats such as 4680 [13, 41].

While the existing production capacity for cylindrical cells in Europe is low, representing about 10% of the 76 GWh total capacity in 2021, it is expected to reach 100 GWh by 2030 [13]**. European LEV players are well-positioned to become ideal off-takers given the rapid growth trajectory and the relatively high share of domestically produced LEVs – representing an estimated aggregated battery demand of up to 21 GWh annually by 2030[8], and up to 85 GWh cumulatively between 2025 and 2030.**

This initial demand could prompt European battery manufacturers to quickly ramp up cylindrical cell production. By establishing cylindrical cells as a cross-application standard format, the European battery value chain could cater not only to the growing demand from e-mobility – incl. LEVs and electric cars, but also to a diverse range of industries such as drones/eVTOL, power tools, residential storage, and as buffers for EV charging stations [13]. **This strategic move has the potential to support the growing LEV market while also diversifying and strengthening the European battery value chain**. Nevertheless, it needs to compete with well-established cylindrical cell suppliers from China, Korea, and Japan (aggregated market share of up to 80%), as well as the growing supply from the US (20% market share) [13].

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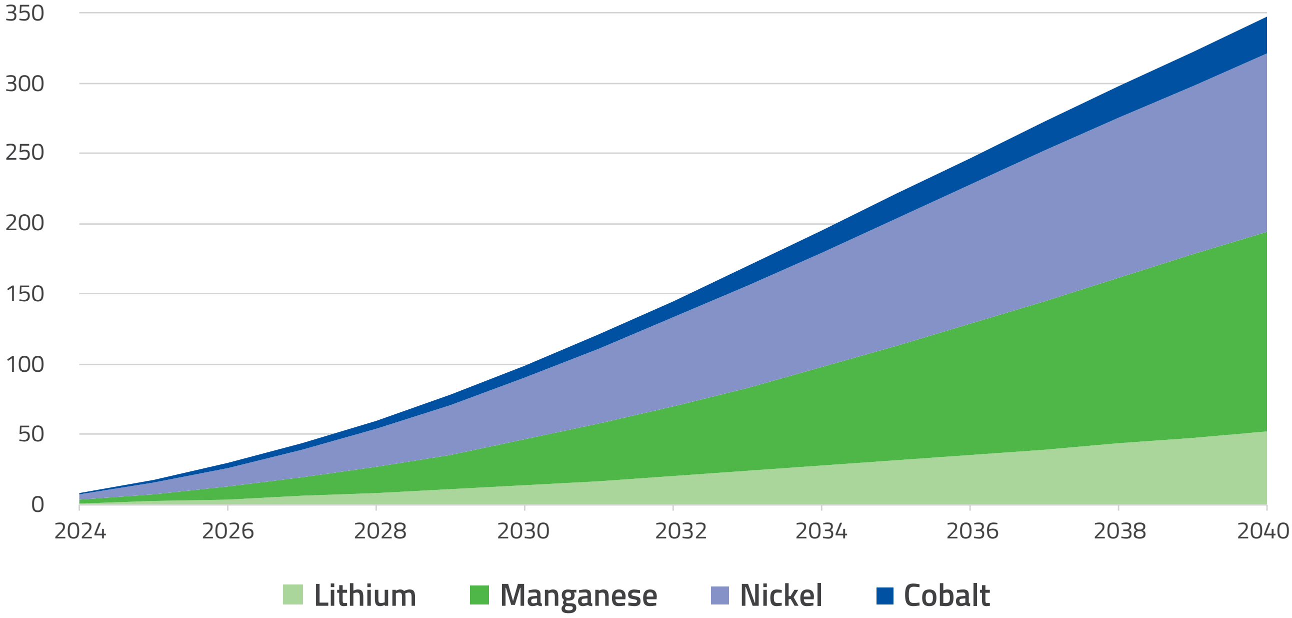
[8] Based on current market projections and accelerated scenarios (see Box 2) for LEVs produced in Europe: Assumes 90% of e-bikes sold (based on CONEBI: 5.5 million units sold and 5.4 million produced and assembled in Europe in 2022, i.e. >90% [18]); assumes 72% of e-two-wheelers sold (based on ACEM: 1.4 million two-wheelers sold (both ICE and electric) of which 1 million were produced in Europe in 2019, also considers that e-two-wheelers represented 28% of total L-category vehicles imports by value that year [21]); assumes 10% of e-kickscooters sold for shared mobility operators, considered ideal off-takers to secure battery demand (based on insights from McKinsey Centre for Future Mobility).

2.1 More Mobility, Fewer Resources: The Impact of LEVs on the Supply of Critical Raw Materials

LEVs can meet a substantial portion of urban mobility needs with smaller batteries and fewer material resources than electric cars [9]. In 2020, the estimated tonnage of LEV batteries placed on the market was ten times smaller than that of electric car batteries [38], but the number of LEVs sold was almost three times greater [8]. Thus, **LEVs can support the EU's ongoing efforts to transform and decarbonise road transport, with minimal demand for critical material supply:**

- **By 2030, the cumulative demand for critical materials for LEV batteries was estimated to be 13.7 kt of lithium, 8.8 kt of cobalt, 44.2 kt of nickel, and 39.4 kt of manganese.** This demand pales compared to electric cars, requiring over 20 times more lithium and nickel and over 10 times more cobalt and manganese. [22].
- **By 2040, the cumulative demand will rise to 51.8 kt of lithium, 25.6 kt of cobalt, 127.4 kt of nickel, and 142.0 kt of manganese**. This considers the introduction of energy-dense nickel- and manganese-rich chemistries and new sodium-ion chemistries with no lithium or cobalt requirements. Despite this increase, the cumulative demand for lithium and cobalt in electric cars will still be around 20 and 10 times higher than that of LEVs, while nickel will be nearly 30 times more significant, and manganese is almost 20 times more. [22].

Figure 2. Cumulated critical material demand from LEVs
(thousand tonnes)



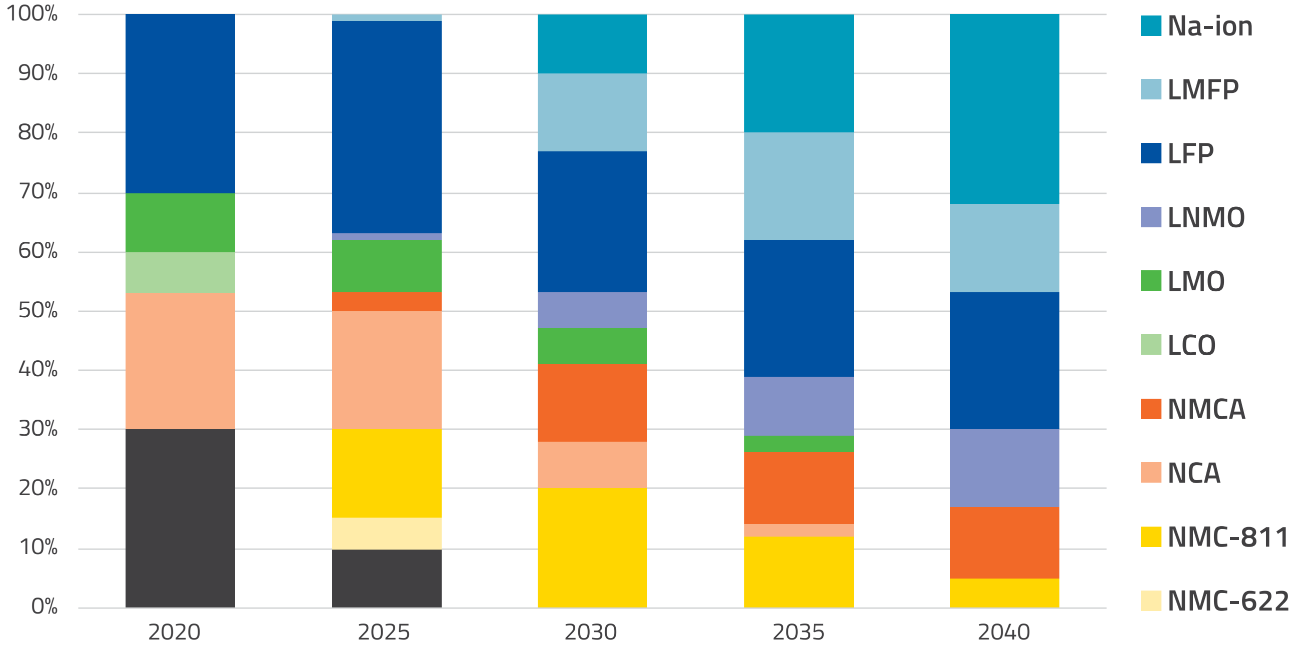
Source: Based on data from BloombergNEF and own analysis.

The expected demand for critical materials for LEV batteries, primarily lithium, nickel, cobalt, and manganese, was estimated by considering the sector's total battery demand and the projected evolution of various battery chemistries, including their compositions and energy densities (based on data from Bloomberg NEF and IEE, and our own calculations).

In 2020, high-performance chemistries such as **NMC111** and **NCA** accounted for an estimated 60-70% share of Europe's LEV battery chemistry mix [38], mainly due to the rapid adoption of high-end e-bikes (including e-cargo bikes) and the increased demand for electric two-wheelers. These chemistries are expected to be replaced by next-gen nickel-rich options, such as **NMC622** and **NMC811**, to increase overall performance, as well as high-manganese **NMCA** cathodes to improve cost efficiency [22, 41]. **Despite high degradation concerns, LMO cells will retain a small share in some LEV applications**, as they have fewer internal heating problems in smaller packs. However, they will eventually be replaced by introducing more durable high-nickel **LNMO** chemistries [41, 42].

Low-cost **LFP** chemistries represented around 30-40% in 2020 [38], with a high share in the mass-market LEV segments. Assuming technological advances in recyclability enable wider adoption, LFP is expected to penetrate higher-end LEV segments as energy density increases, especially with new manganese-rich variants such as **LMFP** [22, 41]. Finally, **Na-ion** batteries are expected to grab a share of mass-market segments post-2030, following a similar trajectory to LFPs [22]. However, their delayed market entry may hinder competition with Li-ion technologies as Li-ion battery supply chains continue to expand [22].

Figure 3. Evolution of battery chemistry mix – LEVs
(% Share)



Source: Based on data from BloombergNEF, Urban Mine Platform, and own analysis

LEVs could also help reduce some of the demand for critical raw materials from passenger cars, by reducing car use and kilometres travelled in cities. Broader LEV adoption would impact car ownership – e.g., fewer cars per household or keeping them for longer, leading to a slight reduction of annual electric car sales of no more than 1-2% by 2030 [12]. In fact, T&E has estimated that policy measures to reduce car kilometres, including shifting to alternative transport modes and increasing car-sharing and car-pooling, could cut critical raw material demand by 7-9%, and up to 18-22% with more aggressive policies [43]. However, T&E also highlights that downsizing the battery -or the vehicle itself- is the single largest contributing factor to reducing critical material demand, achieving a 19-27% reduction [43].

Overall, the uptake of LEVs can be an effective strategy for optimising the utilisation of critical resources while addressing urban mobility challenges. Compared to small electric cars, LEVs require far fewer resources and less space, easing traffic congestion and reducing CO_2 emissions. Moreover, LEVs offer an affordable and more active form of travel, contributing to improved public health and road safety. While automakers should gradually introduce small electric car models, LEVs are already available today and at scale.

3 From cells to two-wheels: Accelerating the uptake of LEVs with Current and Future Battery Technologies

As mentioned previously, LEVs are already available at scale today, but to effectively support their widespread adoption and meet the demand from the shift in short urban trips from passenger cars, it is essential to understand how battery technologies can enhance their safety, performance, and affordability while reducing their carbon footprint. These factors collectively shape the market and are crucial considerations for both industry players and policymakers.

3.1 LEV battery requirements and technologies

Despite their historical dominance due to low cost, lead-acid (Pb-A) batteries are rapidly being replaced by lithium-ion (Li-ion) batteries due to their superior energy density, performance, and falling prices [22], leading to a nearly complete adoption in high-income markets like Europe, Japan, and the US [44].

Battery requirements can vary widely across different LEV applications (see **Table 1**). For example, e-kickscooters use more compact batteries but still require relatively higher power output to complete their shorter trips on average without pedal assist, compared to e-bikes [40]. However, the high utilisation (charging cycles) of shared e-kickscooters can reduce battery lifetime from 5 to 2 years, so operators seek durable batteries to maximise the economics of asset utilisation [45]. In contrast, performance-oriented LEVs, such as e-motorcycles and high-power e-scooters, require larger battery capacity to travel longer distances, so OEMs seek higher energy densities to reduce size while increasing overall efficiency and range [46].

	E-kick scooters	E-bikes (<25 km/h)	E-mopeds (<40 km/h)	E-scooters (<70 km/h)	E-motorcycles
Capacity [kWh]	0.28 – 1.3	0.5 – 1.7	1.4 – 4.8	1.4 – 4.8	14 – 21
Weight [kg]	0.8 – 4.2	2.0 – 6.5	8 – 20	8 – 25+	60 – 62.7
Range [km]	32	60	32 – 80	80	180
Lifetime [years]	1.5 – 3	8.5 -11	2.5 – 7	3 – 10	9 – 11

Table 1: Typical battery characteristics for micromobility vehicles [9]

Affordability and consumer acceptance play pivotal roles in driving the adoption of LEVs. According to a global consumer sentiment survey, 48% of consumers stated affordability as the top factor for selecting a transport mode [47]. This has implications for three key battery-related metrics: Cost, Safety, and Overall Performance.

Battery Cost

As batteries make up 35-50% of the BOM of LEVs [29, 30], **reducing battery costs would not only make LEVs more affordable but also enhance the industry's competitiveness,** allowing manufacturers to offer competitively priced products and helping shared micromobility operators improve their profitability.

Following the pandemic e-bike boom, sales dropped by 8% in 2023 [48], primarily due to high inflation limiting consumer spending on big-ticket items [49] [50]. Price remains a sticking point; although 47% of Europeans see e-bikes as a cost-saving solution, 54% find the upfront costs too high [51], likely to rise due to increased production and components costs as of 2024 [49]. Similarly, the price gap between electric two-wheelers and their ICE counterparts has also held back sales growth [52], with new registrations of e-mopeds and e-motorcycles falling by 29% and 20% in 2023 [21]. This also has implications for shared micromobility operators, who face pressure to cut costs and increase their tight profit margins [53].

Battery chemistry is a key driver of cost reduction since material costs represent 60-80% of the total cell costs [13]. LFP (lithium iron phosphate) is a low-cost chemistry prioritising affordability over performance. While LFP adoption in electric cars is mainly concentrated in China at 70% in 2023, it is much lower in Europe at 6% [54]. In contrast, European LEVs, especially mass-market segments, have significantly embraced LFPs, with 50% of e-bike batteries using this chemistry in 2020 [38]. LFP cells are roughly 15% cheaper per kWh than nickel-based cells [55], primarily due to the lack of costly nickel and cobalt, which also makes them more resilient to metal price shocks and supply chain bottlenecks [55]. Despite cost advantages, LFP chemistries face three critical challenges:

- **Low energy density and specific power:** With 10-36% less energy density compared to nickel-based chemistries [22], LFP cells result in larger, heavier batteries that can constrain compact LEV designs, as well as non-pedal-assisted applications that require high power output. However, improved manufacturing processes and cell advancements, such as adding manganese (LFMP), aim at making their energy density more competitive [22, 13].
- **Low-value recyclability:** LFP battery recycling is complex and energy-intensive, yielding high impurity residues [56]. And without high-value materials such as cobalt and nickel,

the process could be less profitable [22]. Moreover, high recycling costs could erode LFP cost advantages as stricter mandates on battery-recycled content come into force (see Section 4.1). However, retired LFP batteries have a higher potential for second-life application [57].

- **Low domestic production:** Most LFP cells are imported from China, covering over 95% of the global LFP production, creating vulnerabilities in the supply chain [58]. Europe's minimal LFP cell production capacity is projected to reach nearly 25% by 2030 [58].

Battery Safety

Battery safety is crucial for LEVs, as it affects the confidence of both consumers and policymakers in their broader adoption. The widespread use of lithium-ion batteries, which are highly reactive and prone to thermal runaway, poses significant risks of fires and explosions if damaged, mishandled or improperly charged [59]. Between 2020-2022, the Netherlands reported 327 fires involving 690 LEVs, primarily e-scooters and e-bicycles, but technical defects caused 35%, possibly linked to poor quality and inadequate design [60]. This figure underscores the significant impact of battery handling and charging practices from private users and micromobility operators, even with the already stringent EU safety regulations for new batteries entering the market [8].

LFP cells have also emerged as a safer battery alternative due to their superior resistance to overcharging and thermal runaway, operating effectively at wider temperature ranges [61]. Additionally, LFP batteries offer nearly double the cycle life of other chemistries [62], reducing the frequency of replacements and associated risks. While adopting safer chemistries like LFP can significantly mitigate risks, further research is still needed to develop innovative battery management systems, especially for LEVs, which are more susceptible to impacts and damages [8]. Nonetheless, improved safety standards and public awareness are still crucial to enhancing battery safety and preventing undesirable actions like blanket bans on LEVs, which would hinder the necessary modal shift from passenger cars to more sustainable modes of transportation.

Battery Performance

Battery performance is an enabling factor for the electrification of the two-wheeler segment, as it directly affects consumers' demands and concerns about range, weight, and overall drive experience [52, 63]. While most two-wheelers boast ranges of 200-320 km, the range nearly cuts in half at highway cruising speeds, given their reduced aerodynamics and lack of regenerative braking [63], impacting charging times and frequencies when commuting longer distances, especially with a lack of adequate charging infrastructure [46]. The extra weight of the battery pack can also impact manoeuvrability and driving efficiency, hindering a smoother and more responsive driving experience [63]. **Battery performance is thus critical to making LEVs a more attractive and viable alternative to their ICE counterparts.**

Nickel-based performance chemistries are designed to achieve high energy densities for longer driving ranges and lighter battery backs – with NCA (nickel cobalt aluminium oxide) and NMC (nickel manganese cobalt oxide) being the most widely used [22]. However, they can contain up to five times more nickel and three times more cobalt than lithium, which are highly costly and volatile metals [54, 55]. LMO chemistries (lithium manganese oxide), which substitute nickel with relatively cheaper manganese, have been used to reduce costs, but their shorter lifespan and degradation issues have limited wider adoption [42]. However, new developments aim to integrate either nickel or manganese into chemistries such as LNMO (lithium nickel manganese oxide) or NMCA (nickel manganese cobalt aluminium oxide) to strike a better cost-performance balance [22]. These mid-cost, mid-performance chemistries could be pivotal in accelerating the adoption of electric two-wheelers by addressing two major consumer concerns: Affordability and Performance.

The industry's efforts to balance battery performance (weight, range, life cycle), cost, and safety directly impact the chemistry used in today's LEV batteries and the development and adoption of future battery cell technologies.

3.2 Future LEV battery cell technologies

As more electric cars hit the road, there is a growing demand for high-performance chemistries to achieve longer driving ranges and faster charging, as well as low-cost chemistries that use cheaper and more abundant materials to achieve mass-market adoption and alleviate supply chain bottlenecks. **This has led to advances in several promising future battery technologies, each of which will be deployed differently across the various LEV applications depending on the optimal balance between performance and cost**. The two most relevant next-generation technologies for LEVs are:

1. **Sodium-ion (Na-ion) batteries for affordability.** These batteries replace lithium entirely with sodium, a more abundant material that is six times cheaper,[9] thus leading to lower battery pack costs.[10] Despite their lower energy density than LFP cells, Na-ion batteries offer comparable technical performance, lower costs, and enhanced safety, making them competitive enough to carve out a share of the Li-ion market [22]. While further developments are still necessary to improve Na-ion's lifecycle and pack-level energy density to compete with current LFPs, commercialisation efforts are well underway. The first commercial-scale factory to serve the small electric car and LEV segments has been announced in China [64]. Meanwhile, in Europe, Northvolt is in the pre-commercialization phase of a Na-ion cell with a 160Wh/kg energy density, on par with current LFPs.
2. **Solid-state batteries for performance.** These batteries replace the gel-like electrolytes of Li-ion batteries with solid-sate materials (solid oxide and sulphide) to enhance energy density and safety [42]. Due to higher manufacturing and raw material costs, mass production timelines are expected for 2030 and onwards, primarily for high-end vehicle models [22]. They are thus most suitable for e-motorcycles, high-power e-scooters, and high-end or off-road e-bikes.

As electric car sales gradually increase, advancements in battery technologies will continue to trickle down to LEV applications, capitalising on price reductions from mainstream adoption. However, simply borrowing innovations from electric cars is not as straightforward, given the unique challenges and requirements of LEVs. With the number of new LEVs hitting the roads already outpacing electric cars, it is thus essential that research and funding are also made available to the LEV segment to address critical issues such as safety, affordability, and customer acceptance, ensuring their continued growth and contribution to the EU's climate and industrial objectives.

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[9] Comparison from the Shanghai Metal market: Battery grade sodium carbonate price (avg. 28/05/2024): 702,84 USD/mt Lithium carbonate (99.5% battery grade, same day): 14678,27 USD/mt

[10] For example, CATL's sodium-ion battery for electric cars costs ~30% less than LFP [54]

4 Closing the Loop: Minimising the carbon footprint of LEV batteries

The LEV battery value chain needs to be circular to fully contribute to the sustainable urban mobility transition. In Europe, a range of regulatory and non-regulatory initiatives set out complementary criteria to enhance the circularity of the battery value chain.

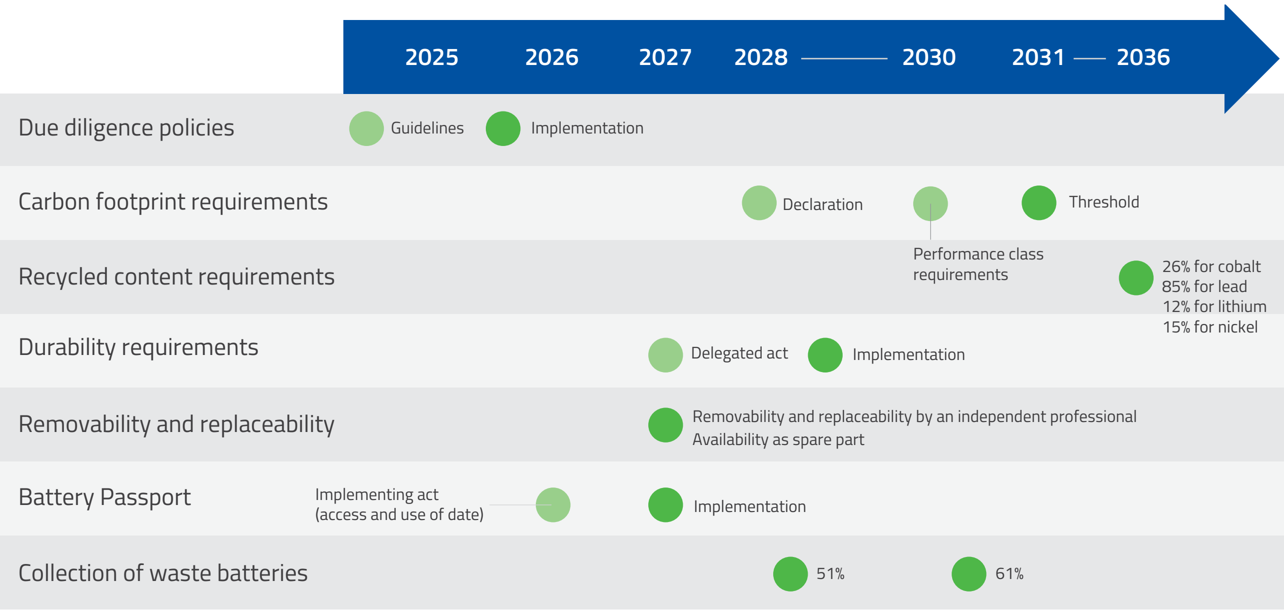
4.1 The emphasis on circularity in the battery regulation

Regulations and standardisation are crucial in boosting LEV uptake and supporting the LEV battery industry. The European Commission has introduced a new regulation concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC [66]. The new Regulation came into force in August 2023 and started to apply as of February 2024.

Below are the key provisions for LEV batteries:

- **Due diligence** for all batteries placed on the market, with a carbon footprint threshold to be defined in the case of LEV batteries in a delegated act by February 2030. Batteries exceeding this threshold will not be allowed on the EU market. It is one of the most robust provisions in the text.
- **Recycled content requirement**: New batteries must contain a minimum amount of recycled content. The amounts to be recovered apply from 2036 onward and are—where applicable—set in the regulation as follows: 26% cobalt, 85% lead, 12% lithium, and 15% nickel.
- **Durability requirements**: minimum values for electrical performance and durability. A threshold will have to be met, to be defined for LEV batteries in a delegated act by February 2027.
- **Battery removal and replaceability. This needs to happen as of 2027 in the LMT segment and applies to individual cells and packs. Independent professionals must be able to remove and replace them**.
- **The battery passport** with which you can track much battery information. The exact data to be collected is still under discussion.
- **Collection targets** for waste LMT batteries: 51% by 2025, 61% by 2031

Figure 4. Timelines for the New EU Battery Regulation - LEVs



Source: Own production based on the new EU Battery Regulation [66].

4.2 Recommended actions to enhance circularity and sustainability

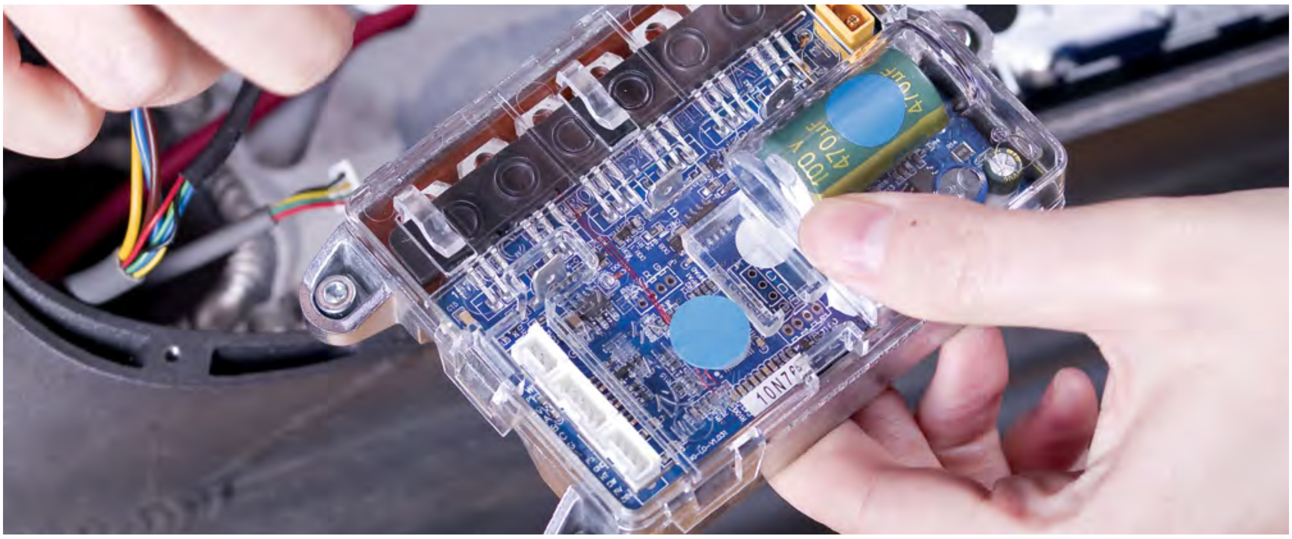
The challenges listed below are slowing the transition of LEV battery value chains towards more circularity and sustainability. This section puts forward recommendations to address these challenges:

Industrial and R&D priorities:

- An effective circular strategy for LEV batteries should prioritise minimising the usage of critical materials and promoting reuse before considering recycling and energy recovery. LEVs already use fewer materials (as shown in section 2), and their operational requirements make them more suitable than EVs for battery chemistries that use significantly fewer critical materials (e.g., LFP and Na-ion).

- Today, LEV batteries, while included in the new EU battery regulation, remain on the fringes of the EU industrial policy and research agenda. This is a missed opportunity considering the materials-saving benefits LEVs offer (see part 2.1).

- Specific training is needed for handling and repairing LEV batteries, as skilled labour is crucial in dealing with battery pack complexity.



Framework for battery repair:

- Repairing battery packs by replacing faulty cells or electronic components can significantly prolong their usefulness.
- However, while the Battery Passport will improve the situation, this approach needs to become less academic and more operational, e.g. including more transparency on dynamic data such as batteries' state of health and proper diagnostics of the BMS: showing to the operators the SoH of batteries and suggesting solutions on this basis (e.g. keep, repair, recycle) let operators understand that circularity is profitable.
- Strong safety and liability warranties for operators can increase their acceptance to having their batteries repaired.
- The grey area around the certification of already certified cells and used cells need to be clarified, especially when, after being repaired, these cells meet the initial manufacturer requirements.

Battery collection:

- Reusing (LEV) batteries in second-life stationary applications extends the product's value – improving batteries' total cost of ownership - and the materials used. For instance, in cases where battery parts are in excellent condition but need replacement, these can be repurposed during the remanufacturing of another vehicle's battery pack. Batteries with remaining capacity and potential for a longer lifespan can be reused in stationary settings.
- However, the potential for second-life usage and the development of a dedicated industry is being slowed down by hoarded batteries: many companies are hoarding batteries, expecting that recycling costs will reduce in the future or that they even receive compensation for having their batteries recycled because of the value of the materials inside.

Battery pack design:

- The design of battery packs used by various manufacturers, including their sizes, cell shapes, and chemistries, can significantly impact repair and recycling rates and the overall battery lifetime. A report by the International Institute for Industrial Environmental Economics for the European Environmental Bureau shows that modular design and reversible casing and joining techniques do not compromise ingress protection, weight, or safety requirements [67]. Such design, however, can enable safer repairs for professionals.
- Today, dismantling battery packs is challenging due to their complexity and variety – not only at the cell level but for components like Battery Management Systems, cooling systems, control electronics, and cables. It is estimated that hundreds of different battery pack designs, sizes, and connectors are currently serving the LEV market, making it harder to build a circular value chain. This means that to recycle LEV batteries effectively, they must be sorted based on their chemistries, sizes and cell shapes to enhance material purity.

Use of recycled material:

- The new battery regulation sets a target for the minimum amount of recycled material in new batteries. In this regard, LEV batteries should use as much recycled material as possible, and it should be investigated whether LEVs can reuse automotive batteries. For some LEV subcategories, energy density is less important than cost.
- However, the lack of standardisation in dismantling processes and clear collection point guidance for users makes the process more complex and less feasible. Today, the regulation does not specify where the recycled material should come from. This raises the question of whether the minimum content can be satisfied only with EU recycling and what the impact on recycling prices will be.

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About EIT InnoEnergy

EIT InnoEnergy operates at the centre of the energy transition and is the leading innovation engine in sustainable energy. It brings the technology, business model innovation and skills required to accelerate the green deal, progress towards Europe's decarbonisation and re-industrialisation goals, whilst also securing a reliable supply of clean energy.

Recognised as Europe's top cleantech and blue economy venture capital firm and investor in 2023 by Startup Genome, one of Europe's top 10 most active deeptech investors by Sifted in 2023 and the most active investor in the energy sector in 2022 by Pitchbook, InnoEnergy backs innovations across a range of areas. These include energy storage, transport and mobility, renewables, energy efficiency, hard to abate industries, smart grids and sustainable buildings and cities.

InnoEnergy has a portfolio of more than 200 companies, which are estimated to generate €110 billion in revenue and save 2.1G tonnes of CO2e accumulatively by 2030. Collectively, these companies have raised more than €9.7 billion in investment to date.

InnoEnergy is the driving force behind three strategic European initiatives which include the European Battery Alliance (EBA), the European Green Hydrogen Acceleration Center (EGHAC) and the European Solar Photovoltaic Industry Alliance (ESIA).

InnoEnergy was established in 2010 and is supported by the European Institute of Innovation and Technology (EIT), a body of the European Union. Since its inception, InnoEnergy has screened more than 7,000 start-ups, launched more than 300 products to market and overseen its portfolio companies filing 370+ patents. Today, InnoEnergy has a trusted ecosystem of 1200+ partners and 35 shareholders and a 200+ strong team with offices across Europe and in Boston, US. www.innoenergy.com

About EIT Urban Mobility

EIT Urban Mobility, an initiative of the European Institute of Innovation and Technology (EIT), a body of the European Union, aims to accelerate solutions and the transition towards a user-centric, integrated and truly multimodal transport system. As the leading European innovation community for urban mobility, EIT Urban Mobility works to avoid fragmentation by facilitating collaboration between cities, industry, academia, research, and innovation to solve the most pressing mobility challenges of cities. Using cities as living labs, its industry, research, and university partners will demonstrate how new technologies can work to solve real problems in real cities by transporting people, goods, and waste in smarter ways.

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