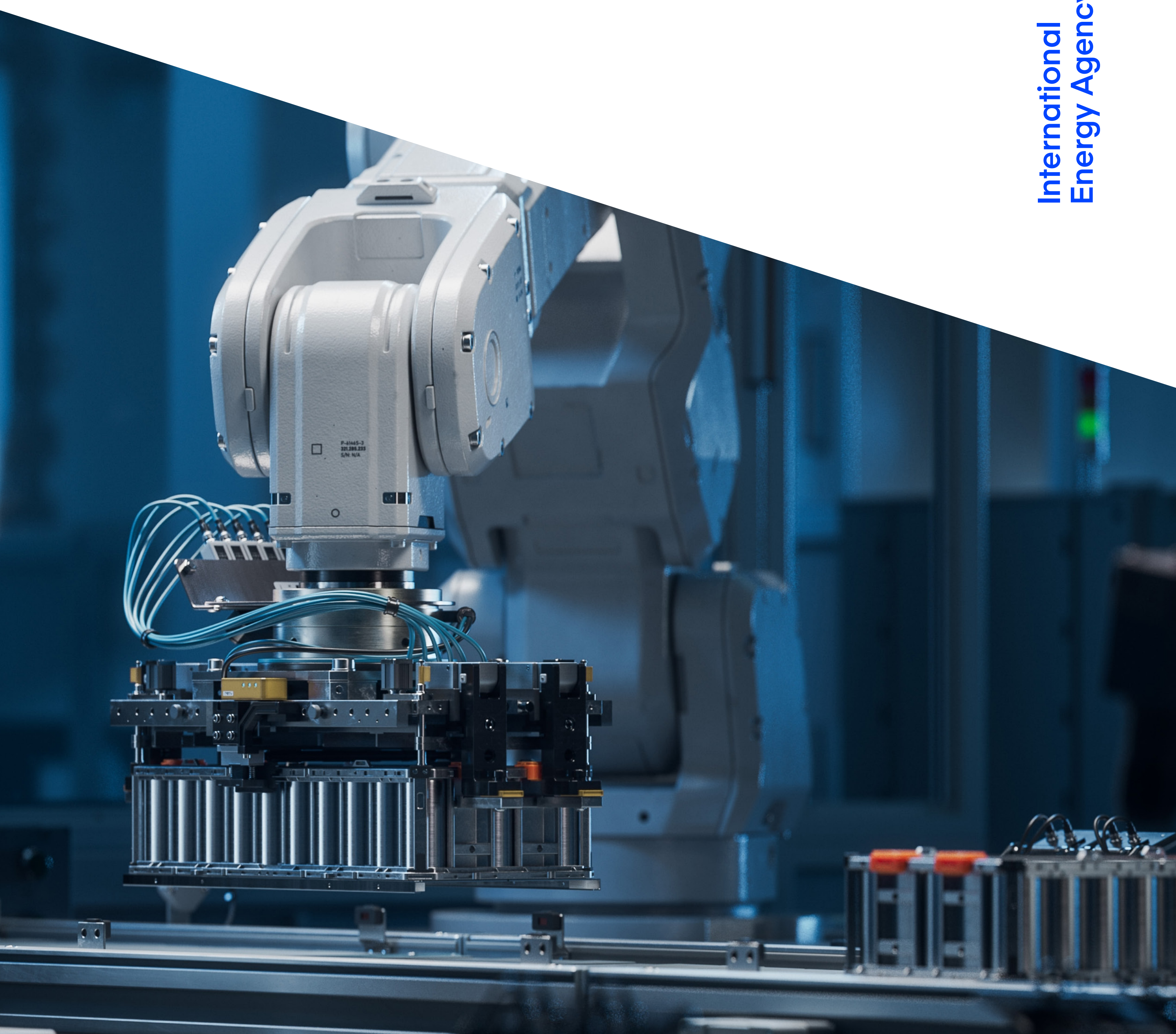
EV Battery Supply Chain Sustainability

Life cycle impacts and the role of recycling



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Highlights

- Battery demand is set to continue growing fast based on current policy settings, increasing four-and-a-half times by 2030 and more than seven times by 2035. The role of emerging markets and developing economies (EMDEs) other than People's Republic of China (hereafter, "China") is expected to grow, reaching 10% of global battery demand by 2030, up from 3% in 2023. Battery production is also expected to diversify, mostly thanks to investments in Europe and North America under current policies, and – if all announced climate pledges are fulfilled – through larger demand and production in EMDEs other than China.
- From a life cycle perspective, the emissions of a medium-size battery electric car are half the emissions of an equivalent internal combustion engine (ICE) car as a global average. This difference in emissions is similar to the global average in China, larger in the United Kingdom and Chile (over 60%), and smaller in India (20%).
- Battery-related emissions play a notable role in electric vehicle (EV) life cycle emissions, though they are not the largest contributor. However, reducing emissions related to battery production and critical mineral processing remains important. Emissions related to batteries and their supply chains are set to decline further thanks to the electrification of production processes, increased energy density and use of recycled materials.
- In the next decade, recycling will be critical to recover materials from manufacturing scrap, and looking further ahead, to recycle end-of-life batteries and reduce critical minerals demand, particularly after 2035, when the number of end-of-life EV batteries will start growing rapidly. If recycling is scaled effectively, recycling can reduce lithium and nickel demand by 25%, and cobalt demand by 40% in 2050, in a scenario that meets national climate targets. Scaling up recycling facilities and increasing collection rates of end-of-life batteries will be essential.
- Second-hand EVs could boost electric mobility in EMDEs other than China. Strengthening international co-operation is central to support international trade of second-hand EVs while ensuring adequate end-of-life strategies for the vehicles and their batteries.

Acknowledgements

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The role of batteries is expected to keep growing

Electric cars remain the main engine of battery demand growth

Growth in EV sales and battery storage[1] installations continue to drive battery demand, which reached 850 GWh in 2023, up more than 40% from 2022. EVs remain the main source of battery demand, accounting for 750 GWh or almost 90% of the total in 2023, with electric cars alone representing about 80% of total battery demand. Battery storage demand doubled in both 2022 and 2023, albeit from a lower base than demand for EV batteries.

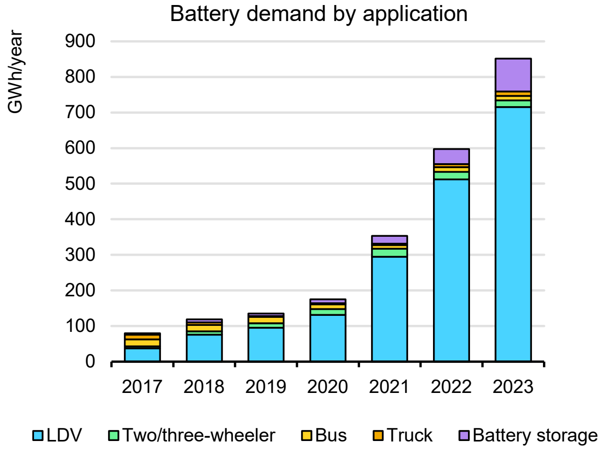
Overall battery demand in the European Union and the United States grew faster than the global average in 2023, reaching 45% year-on-year, closely followed by China at 40%. In terms of total volume, China remains the largest battery market, accounting for about 55% of global demand in 2023, followed by the European Union and the United States, at about 15% each. EMDEs other than China today account for a small share of total battery demand, but their role is expanding. In 2023, their share in global battery demand reached more than 3%, nearly double that just 2 years earlier. India accounted for almost one-third of battery demand in EMDEs other than China.

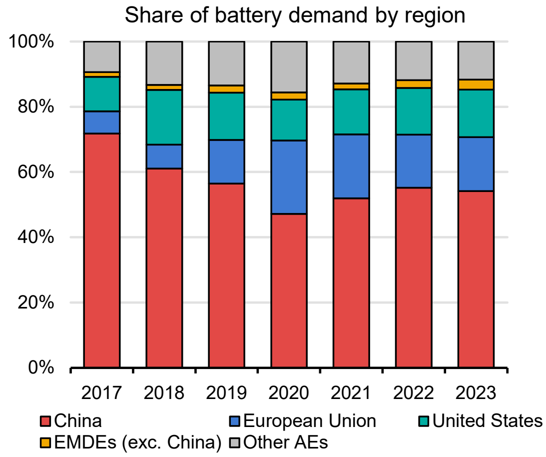
The battery storage market is growing fastest in China, where demand for battery storage systems reached 45 GWh in 2023, almost triple the demand in 2022. Demand for battery storage is driven by the growth in renewable energy, with China installing more intermittent renewable capacity than the rest of the world combined in 2023. In the United States and the European Union, the battery storage market grew faster than the EV battery market, but significantly slower than in China, with year-on-year growth of nearly 65% and over 80%, respectively. This is equivalent to an additional 25 GWh of battery storage in the United States and 12 GWh in the European Union. Markets for battery storage are still nascent in EMDEs other than China, with less than 1 GWh in total added in 2023. More than half of this demand came from Southeast Asia, followed by Africa and then

[1] Battery storage refers to batteries used in the electricity sector. They include both large utility-scale and smaller behind-the-meter battery storage systems. Utility-scale batteries are connected directly to transmission or distribution networks (front-of-the-meter) and typically range from several hundred kWh to multiple GWh in size. Behind-the-meter battery storage systems are generally installed at residential, commercial or industrial end-user locations, without a dedicated connection to the grid. They are usually (but not always) significantly smaller than utility-scale batteries.

India, each representing a share of around 15%. Higher cost of capital is a major reason for lower battery storage investments in those regions, with the cost of capital for battery storage projects being at least twice as high as in advanced economies.

Battery demand by application and region, 2017-2023





Notes: LDV = light-duty vehicle, including cars and vans; EMDEs (exc. China) = emerging markets and developing economies excluding China; AEs = Advanced economies. Battery storage refers to the demand for new installations.
Source: IEA (2024), Global EV Outlook 2024.

In 2023, EVs accounted for over 95% of the battery demand in EMDEs other than China, above the global average (almost 90%). Another striking difference from the global average is that a relatively large share (about 25%) of EV battery demand in EMDEs came from two- and three-wheelers (2/3-wheelers) in 2023, despite their batteries being between 5 and more than 40 times smaller than the average electric car battery. This compares to a 3% share in China and less than 0.5% in the European Union and the United States.

This underlines the popularity and importance of this mode of transport in EMDEs, where sales of electric 2/3-wheelers outside of China reached 2 million in 2023, over 90% of which were in India and Southeast Asia, compared to electric car sales of under 400 000. In India and Southeast Asia, half of passenger kilometres travelled on road in 2023 were by 2/3-wheelers. Electrifying 2/3-wheelers in these countries or regions could therefore offer an effective way to electrify a large proportion of road transport that is less battery-intensive compared to electric cars. While 2/3-wheelers and cars provide a similar service, electrifying the entire fleet of 2/3-wheelers in India and Southeast Asia would require only 30% of the batteries needed to electrify their current car fleets, if using their average regional battery sizes in 2023. In China, sales of 2/3-wheelers and electric cars in 2023 reached more than 6 million and 8 million, respectively, and 2/3-wheelers accounted for over 15% of passenger kilometres travelled on road. This compares to less than 5% in the European Union, and less than 1% in the United States in the same year.

Outlook for battery demand and production

Demand for batteries grows strongly in all scenarios

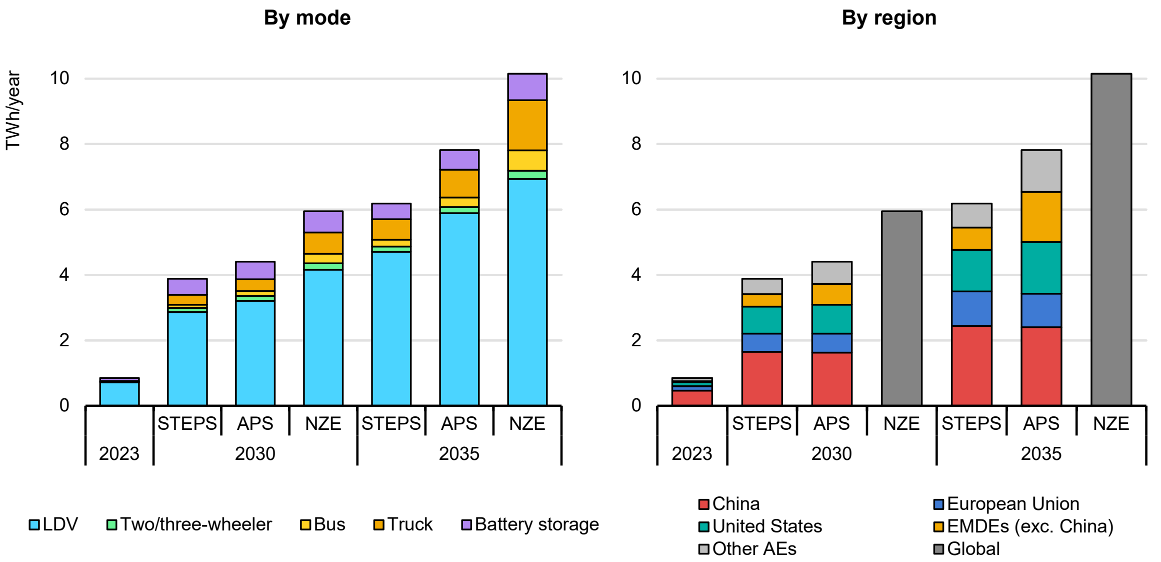
Battery demand is set to grow four-and-a-half times by 2030 compared to 2023 based on current policy settings (as reflected in the IEA Stated Policies Scenario [STEPS]), and more than seven times by 2035. If countries reach their announced climate and energy pledges in full, as in the IEA Announced Pledges Scenario (APS), demand is significantly higher, multiplying by five times in 2030 and nine times in 2035. Demand grows even more in a scenario consistent with the energy sector reaching net zero emissions by 2050, as in the IEA Net Zero Emissions by 2050 Scenario (NZE Scenario), up 7 times in 2030 and 12 times in 2035. To put this in perspective, there is more battery demand per week in 2035 in the APS than there was in the entire year of 2019.

The share of EMDEs other than China in global battery demand also increases this decade, more than tripling to reach 10% by 2030 in the STEPS. The role of these economies is even greater in the APS, with their share of global demand growing almost fivefold by 2030, and more than sixfold in 2035. This is mostly driven by transport electrification strategies and pledges that boost EV battery demand. For example, India signed the COP 26 declaration to reach a 100% sales share of zero-emission light-duty vehicles by 2040, and Indonesia has set an ambition to reach a stock of 2 million electric cars and 13 million electric motorbikes by 2030.

The roll-out of adequate infrastructure, such as chargers, battery-swapping stations, and flexible electricity transmission and distribution grids will be crucial to support growth in EV uptake. As 2/3-wheelers are a popular mode of mobility in some EMDEs, a large share of the population could access electric mobility with home charging, thus avoiding the need for more capital-intensive dedicated chargers.[2] Battery-swapping for 2/3-wheelers could also be an effective solution to boost electric mobility in urban areas.

[2] The battery size of electric 2/3-wheelers is often small enough to recharge at home from a regular domestic socket without installation of a dedicated charger.

Battery demand by mode and by region in the Stated Policies Scenario, Announced Pledges Scenario and Net Zero Emissions by 2050 Scenario, 2023-2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario; LDV = light-duty vehicle, including cars and vans; EMDEs (exc. China) = emerging markets and developing economies excluding China; AEs = Advanced economies. Battery storage refers to the demand for new installations.
Source: IEA (2024), Global EV Outlook 2024.

Efforts to boost domestic demand for EVs and batteries in EMDEs other than China would also be beneficial to attract investments in domestic manufacturing. Long-term visibility and clarity on policy, together with support for domestic demand and production, are central to giving confidence to investors to commit to new projects.

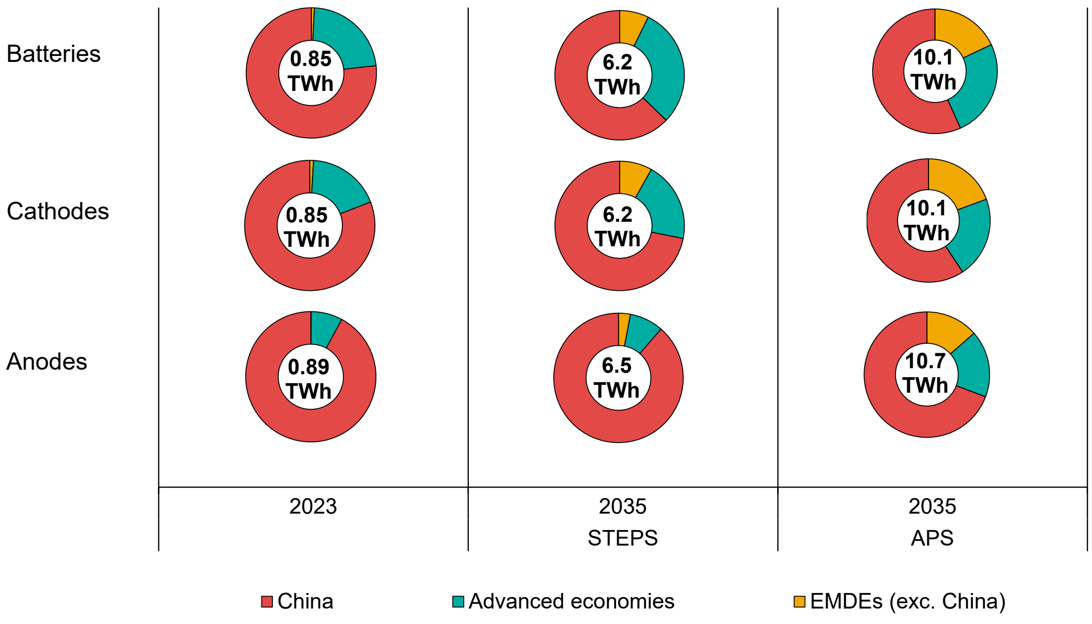
Battery production set to diversify

In 2023, China accounted for the lion's share of the production of battery cells – more than three-quarters – as well as of critical battery components like cathode (over 80% of production) and anode (over 90%) active materials. In the STEPS, battery cell production diversifies, mainly as a result of investments in North America and Europe, with production outside China accounting for almost 40% of the total by 2035. In the APS, alongside higher global demand, battery manufacturing diversifies further, thanks to much larger production of batteries in EMDEs other than China, particularly in India, Southeast Asia and North Africa, together with greater EV and EV battery manufacturing in Europe.

The increase in production in EMDEs other than China is enabled by higher domestic and global demand, combined with lower production costs and access to critical minerals, attracting larger manufacturing investments in these regions. For example, about USD 15 billion in investment in battery and battery component production has been announced in Morocco thanks to its large phosphate reserves,[3] low labour cost and potentially cheap renewable electricity, and free trade agreements (FTAs) with the United States and the European Union. Indonesia has signed more than a dozen deals worth over USD 15 billion for investments in batteries and EVs, and recently inaugurated its first battery cell production plant. If all announced investments come to fruition, as reflected in the APS, Indonesia would become a large EV and battery producer.

Similarly, the production of cathode and anode active material diversifies, but there is a larger gap between the STEPS and APS compared to battery cell production. In the STEPS, China remains by far the largest producer, with Korea and Southeast Asia together representing the second largest source of production, accounting for over 15% of cathode and 5% of anode active material production by 2035. In the APS, greater diversification is driven by larger production in the European Union and the United States, but also, importantly, by much larger production in EMDEs such as India and, for cathode materials, North Africa, and Central and South America.

Battery and selected component production by country or region in the Stated Policies Scenario and Announced Pledges Scenario, 2023-2035



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; EMDEs (exc. China) = emerging markets and developing economies excluding China. Battery refers to battery cells and includes EV and battery storage. A negative (anode) to positive (cathode) electrode ratio of 1.05 is assumed for the final cells, which implies 5% more anode capacity than cathode capacity per cell.
Source: Based on IEA (2024), Energy Technology Perspectives 2024.

[3] Phosphate is a key component of lithium iron phosphate (LFP) batteries.

Many of the minerals needed to satisfy growing battery demand are extracted in EMDEs, such as lithium in South American countries, nickel in Indonesia, and cobalt in the Democratic Republic of Congo. However, despite their excellent mineral and renewable resources, EMDEs other than China account for less than 5% of announced battery manufacturing capacity. This underlines the significant industrial opportunity for EMDEs to play a bigger role in the EV and battery supply chain. Ensuring appropriate environmental, social and governance (ESG) standards will be a necessary precondition for sustainable industrial development projects.

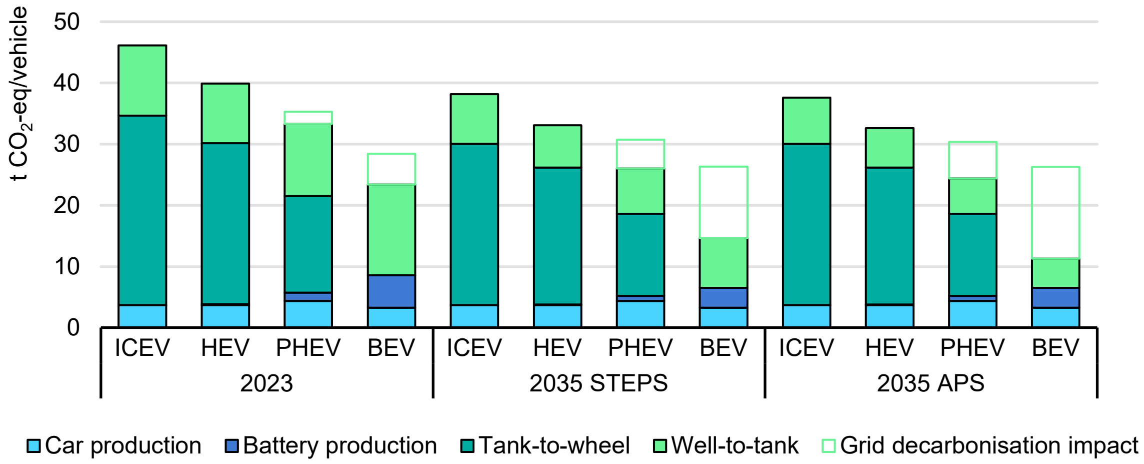
The impact of EVs and batteries on emissions

Electric cars offer emissions benefits today, even when considered on a life cycle basis

Battery electric vehicles are often described as zero-emissions vehicles, though this is only true in terms of emissions while being driven. There are emissions associated with vehicle and battery manufacturing, and with producing the electricity used to recharge the vehicle. Electric and internal combustion engine vehicles (ICEVs) should be compared through life cycle analysis, which includes the emissions associated with the production of the vehicle (and battery) as well as the well-to wheel emissions (i.e. well-to-tank and tank-to-wheel emissions). Under this lens, EVs remain largely beneficial compared to ICEVs, but the extent of the environmental benefits depends on regional conditions such as the electricity mix, driving habits, vehicle size and eventual biofuel share.

For example, as a global average, under current policies, the life cycle emissions of a medium-size battery electric car are about half of those of an equivalent ICEV that is running on oil-based fuels, more than 40% lower than for an equivalent hybrid electric vehicle (HEV), and about 30% lower than for a plug-in hybrid electric vehicle (PHEV) over 15 years of operation, or around 200 000 km. The environmental gain of EVs is also set to increase over time thanks to the decarbonisation of electricity grids. As electricity generation decarbonises more quickly in the APS, these gaps increase by a further 3 percentage points, with BEV life cycle emissions being less than half those of an ICEV, 45% less than an HEV, and about a third less than a PHEV. When comparing vehicles purchased in 2035, as a global average, an ICEV produces two-and-a-half times the emissions of a battery electric car in the STEPS, and more than three times as many in the APS, over the vehicle lifetime.

Comparison of global average medium-sized car life cycle emissions by powertrain in the Stated Policies Scenario and Announced Pledges Scenario, 2023-2035



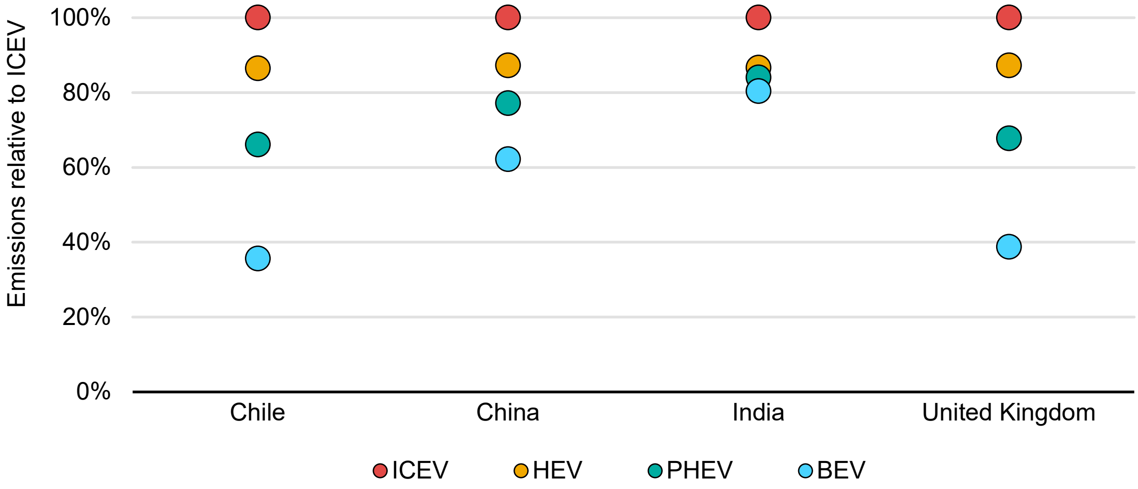
Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle. “Grid decarbonisation impact” refers to the effect of electricity emissions intensity improvements over the lifetime of the vehicle (STEPS used for vehicles sold in 2023). The years 2023 and 2035 refer to the first year of use of the vehicle. PHEV assumes an average utility factor of 40% i.e. 40% of kilometres travelled in full electric mode on average. The impact of biofuel blending is not considered in this analysis. For further details on the assumptions behind this life cycle analysis, please see Annex B of the Global EV Outlook 2024. The impact of varying assumptions is available in the IEA EV Life Cycle Assessment Calculator.

Source: IEA (2024), Global EV Outlook 2024.

Vehicle size plays an important role in determining life cycle emissions. Today, many consumers are choosing larger vehicles than previously, prompted in part by model availability. Though smaller vehicles are clearly preferable in terms of both production and operation emissions across powertrains, the greater efficiency of an electric powertrain means electrification mitigates much of the negative impact of larger vehicles. While some large ICE SUVs can emit up to 50% more emissions than a medium-sized ICE car, a large battery electric SUV emits only around 20% more than a medium-sized battery electric car over its lifetime. Choosing a battery electric SUV over an ICE SUV represents a life cycle emission saving of about 60%. Even compared to a medium-size ICEV, a battery electric SUV results in 40% lower life cycle emissions.

The life cycle emissions benefits of BEVs vary by region, depending, in particular, on the local grid emissions intensity, average annual driving distance, and fuel economy of ICE vehicles. For example, in Chile and the United Kingdom, the life cycle emissions of a medium-size BEV purchased in 2023 are more than 60% lower than those of an ICEV. In the United Kingdom the gap between ICEVs and BEVs is primarily driven by the relatively low and rapidly decreasing emissions intensity of electricity generation. In Chile, the gap between ICEV and BEV life cycle emissions is driven by relatively poor ICEV fuel efficiency as well as the rapid decarbonisation of the power grid, with the average emission intensity of power grids falling by around 70% by 2035 in the STEPS. While BEVs can offer substantial emission reductions when replacing ICEVs, vehicle electrification is not the only strategy to reduce road transport emissions; the use of biofuels, for example, could reduce the life cycle emissions of ICEVs.

Life cycle emissions of a medium-sized car by powertrain relative to a gasoline internal combustion engine car by region in the Stated Policies Scenario, 2023



Notes: ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle. The year 2023 refers to the first year of use of the vehicle. PHEV assumes an average utility factor of 40%, i.e. 40% of kilometres travelled in full electric mode on average. The impact of biofuel blending is not considered in this analysis. For further details on the assumptions behind this life cycle analysis, please see Annex B of the Global EV Outlook 2024. The impact of varying assumptions is available in the IEA online life cycle analysis tool.
Source: IEA (2024), Global EV Outlook 2024.

In China and India, the emissions savings per BEV are lower, due to the higher average emission intensity of their power grids, but the savings are nevertheless significant. In China, the life cycle emissions of a medium-size battery electric car are nearly 40% lower than an equivalently sized ICEV, and the emissions savings are three times more than those offered by an HEV. Despite the emissions benefits of BEVs being lower in China than in Europe and the United States, its larger battery electric car fleet – more than 16 million vehicles in 2023 compared to over 6.5 million in Europe and around 3.5 million in the United States – makes China the leading country for GHG emissions avoided through road electrification.

In India, the life cycle emissions of a medium-size BEV sold in 2023 are 20% lower than of a medium-size ICEV, avoiding slightly more emissions than PHEVs. However, it is worth noting that there are significant efforts underway to decarbonise electricity generation in India: the emissions intensity of the grid falls close to 60% of today's level by 2035 in the STEPS. The environmental benefit of road electrification in India will therefore increase rapidly in the coming years. Even today, electrification can already offer important public health gains by reducing air pollution in India's mega cities like Mumbai.

The IEA online EV Life Cycle Assessment Calculator enables users to explore electric car life cycle emissions and compare them with emissions from different powertrains across different countries, fuel mixes, vehicle sizes and mileages.

Battery chemistry impacts life cycle emissions

The battery market of today is divided between two key families of lithium-ion batteries: nickel chemistries such as lithium nickel cobalt manganese oxide (NMC), which is the chemistry of choice in the United States and Europe, and lithium iron phosphate (LFP), which is the main chemistry employed in China. NMC-type chemistries offer higher energy density, enabling greater EV ranges, but they have a higher critical mineral-intensity and are therefore more expensive. NMC also offers better performance in cold climates. In contrast, lithium is the only critical mineral used in LFP chemistries, which employ more abundant elements, making this chemistry cheaper to produce than NMC. Battery cells reached record low prices in 2024, and LFP cells are roughly 30% cheaper compared to cells using NMC. LFP also offers increased thermal resistance, which increases safety and offers improved performance in hot climates, as well as having a longer cycle life, increasing battery longevity.

The life cycle emissions of batteries include total GHG emissions throughout different steps of the supply chain. This begins with mining and processing of the mined ores to produce precursor materials, which are used to produce the cathode (such as NMC and LFP) and anode (graphite) active materials. The active materials are then used in manufacturing the battery (cells), together with other components like the battery electrolyte, separator, current collector and casing. Lastly, the cells are assembled in battery modules or battery packs with other components such as the battery management systems, the electronics, and the coolant.

Critical minerals processing is the largest source of emissions for high-nickel chemistries, accounting for 55% of total emissions, compared to about 35% for LFP. The higher emissions related to critical mineral processing are the key contributor to NMC batteries having higher life cycle emissions than LFP batteries. Nickel, in particular, which is largely used in NMC batteries, though not in LFP batteries, is an important source of emissions. Today, half of all nickel is mined in Indonesia, and around two-thirds is refined[4] between Indonesia and China using energy-intensive processes and mostly relying on coal as the main energy source.

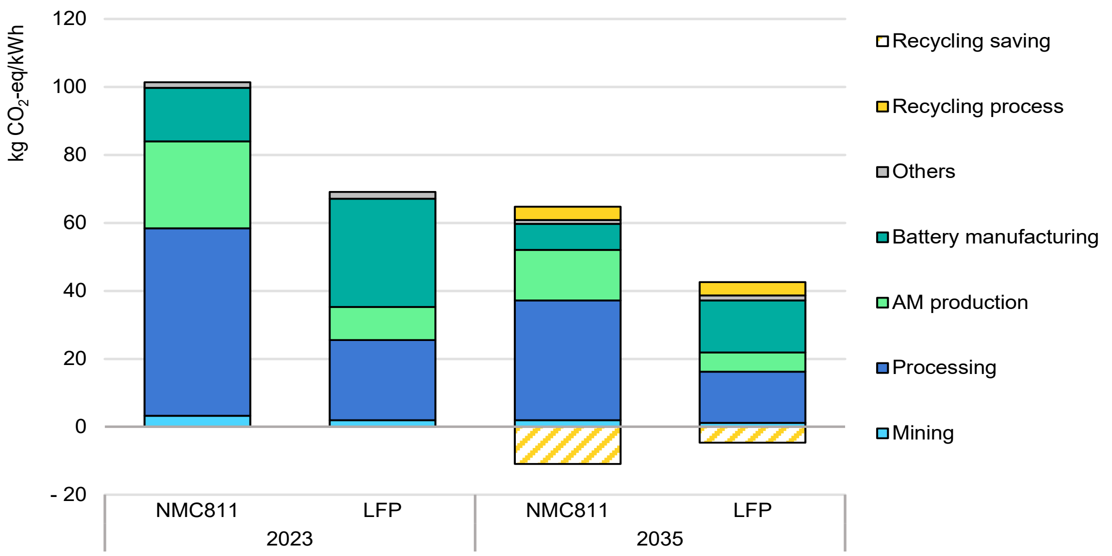
Strategies to reduce emissions in the battery supply chain should be adapted to the targeted chemistry. Reducing emissions from critical minerals processing

[4] After refining, materials are further processed to produce the precursors used to synthetise the cathode active material. Processing and active material synthesis are mainly done in China today for all battery chemistries.

would be the most effective way to bring down total emissions from NMC batteries. Steps towards this aim include sourcing nickel that is less carbon-intensive, decreasing the carbon intensity of current nickel processing operations, increasing recycling content, or decreasing the nickel content of NMC batteries while maintaining high energy density, for example though use of high manganese NMC chemistries. In contrast, battery cell manufacturing is the largest contributor to LFP life cycle emissions, accounting for almost half of total emissions, compared to 15% for NMC. Strategies to reduce LFP emissions should therefore focus on cutting emissions from battery cell production through deeper electrification and the use of low-emissions electricity. In addition, steam, which is used in several battery cell manufacturing facilities, could be produced or sourced from low-emissions energy sources, such as waste heat from nuclear power plants or from other industrial facilities, where available close to battery factories, as well as renewable fuels including biogenic waste.

Battery life cycle emissions decrease by about 35% for both NMC and LFP chemistries by 2035 in the APS, thanks to 30% higher energy density at the battery pack level, in conjunction with decarbonisation of power grids, and sourcing part of the cathode active material through recycling. As more EV batteries reach end of life and become available for recycling after 2035, recycling could play an even larger role in reducing battery emissions, particularly benefiting mineral-intensive chemistries like NMC (see below).

Battery pack life cycle emissions by chemistry in the Announced Pledges Scenario, 2023-2035



Notes: LFP = lithium iron phosphate; NMC811 = lithium nickel manganese cobalt oxide. AM = active material, including both cathode (NMC811 or LFP) and anode (graphite). Battery manufacturing refers to cell and pack manufacturing. End-of-life options other than recycling are excluded from the analysis, and emissions associated with the transport of materials (which are expected to be low) are not considered. Recycling assumes 20% of cathode active material is sourced though recycling. “Others” refers to emissions associated with other battery pack components like electronics and coolant. See Annex B of the Global EV Outlook 2024 for full assumptions.

Source: IEA (2024), Global EV Outlook 2024.

Battery recycling can reduce critical mineral demand and improve sustainability

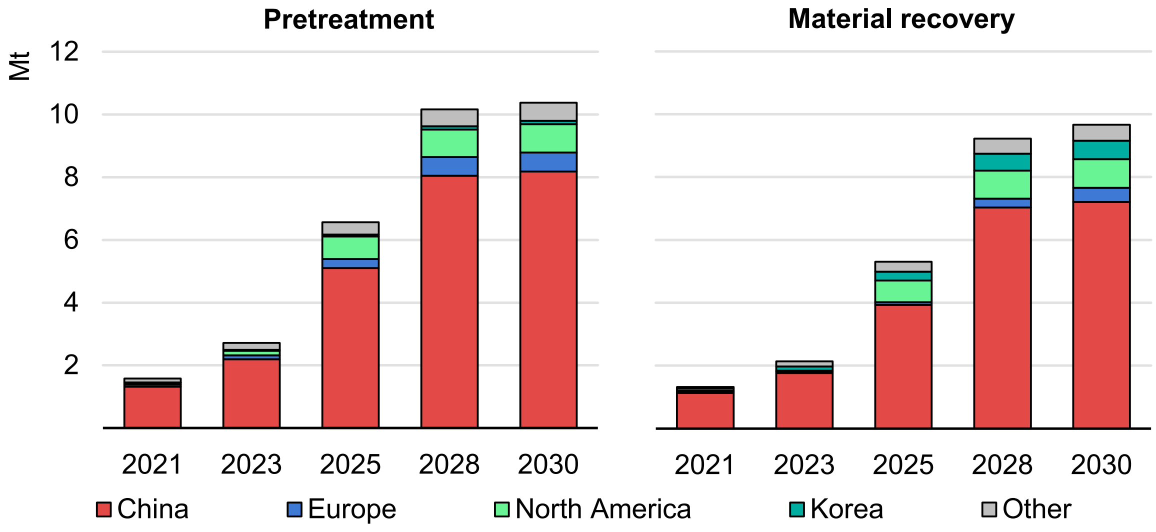
Battery recycling is getting ready for larger supplies in the 2030s

Battery recycling holds the promise of reducing mining demand and battery life cycle emissions. It is expected to enable greater supply chain security and diversification, providing a new source of domestic supply for regions with limited access to critical raw battery materials such as Europe and North America. The extent to which different countries can profit from the advantages of recycling, however, will depend on the availability of recycling capacity and of material feedstock for recyclers.

China accounts for the vast majority of current global battery recycling capacity, with 80% of capacity for battery pretreatment and almost 85% of material recovery.[5] Under the assumption that all announced battery recycling projects are built, some regional diversification would occur this decade, with North America and Europe accounting for 10% and 5% of recycling capacity by 2030, respectively. Korea is also poised to play a significant role, reaching almost 600 kt of material recovery capacity by the same year, more than 5% of the global total. Among EMDEs, announced material recovery capacity in India represents about 2% of the world total, while Southeast Asia and Morocco are expected to reach almost 2% and 1%, respectively. Nonetheless, China is expected to retain 80% of global pretreatment capacity and 75% of global material recovery capacity in 2030.

[5] Lithium-ion battery recycling is typically composed of two main steps: pretreatment and material recovery. Pretreatment refers to batteries being discharged, dismantled, and mechanically or thermally treated to condition them to ease material and metal recovery, typically in the form of black mass. Material recovery refers to the recovery of battery materials and metals after the pre-treatment step.

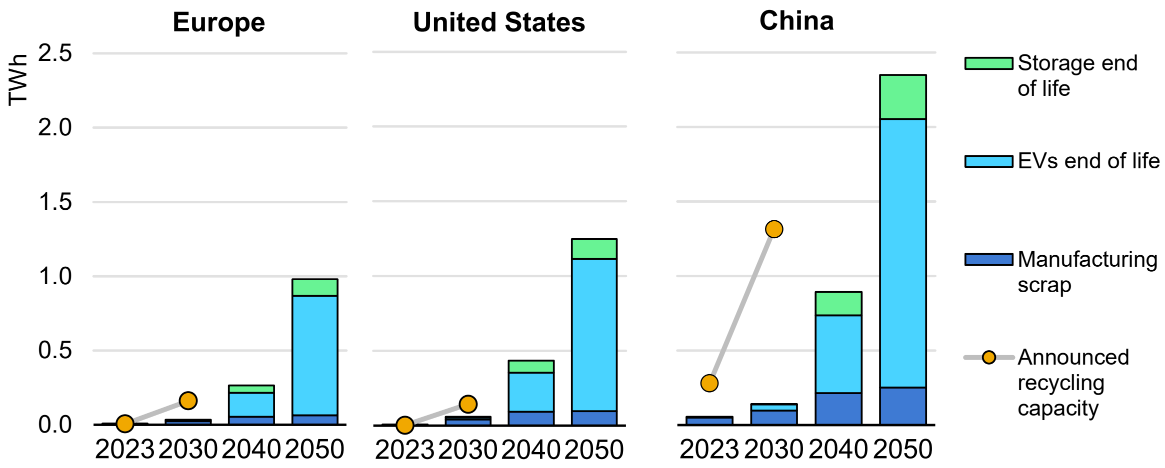
Battery recycling capacity based on announced projects, 2021-2030



Notes: Capacity in megatonnes of cell-equivalent mass of total recyclable material. Announcements include both those that are committed (i.e. under construction or having reached final investment decision) and preliminary announcements (i.e. those that have not reached final investment decision).
Source: IEA (2024), Recycling of Critical Minerals.

Most battery recycling facilities have been planned next to battery manufacturing facilities because the main source of recycling feedstock this decade is expected to be manufacturing scrap (accounting for two-thirds of available stock in 2030). End-of-life EV and storage batteries are anticipated to become the main recycling feedstock only after 2035, representing over 90% of available stock by 2050. As such, in this decade, proximity to manufacturers ensures a competitive advantage for recyclers, with China set to remain the largest battery producer. Nonetheless, the announced recycling capacity in China is significantly higher than the projected available feedstock in the country. Globally, if all announced projects come online as scheduled, global recycling capacity in 2030 could be more than six times larger than total available material feedstock in the APS. This is set to lead to strong competition among recyclers to secure sufficient feedstock to remain profitable over the next decade. However, from 2040, global feedstock increases dramatically, driven by end-of-life EV batteries, reaching 5.5 TWh in the STEPS, almost 7 TWh in the APS, and more than 9 TWh in the NZE Scenario in 2050.

Maximum available battery recycling feedstock and recycling capacity by region in the Announced Pledges Scenario, 2023-2050

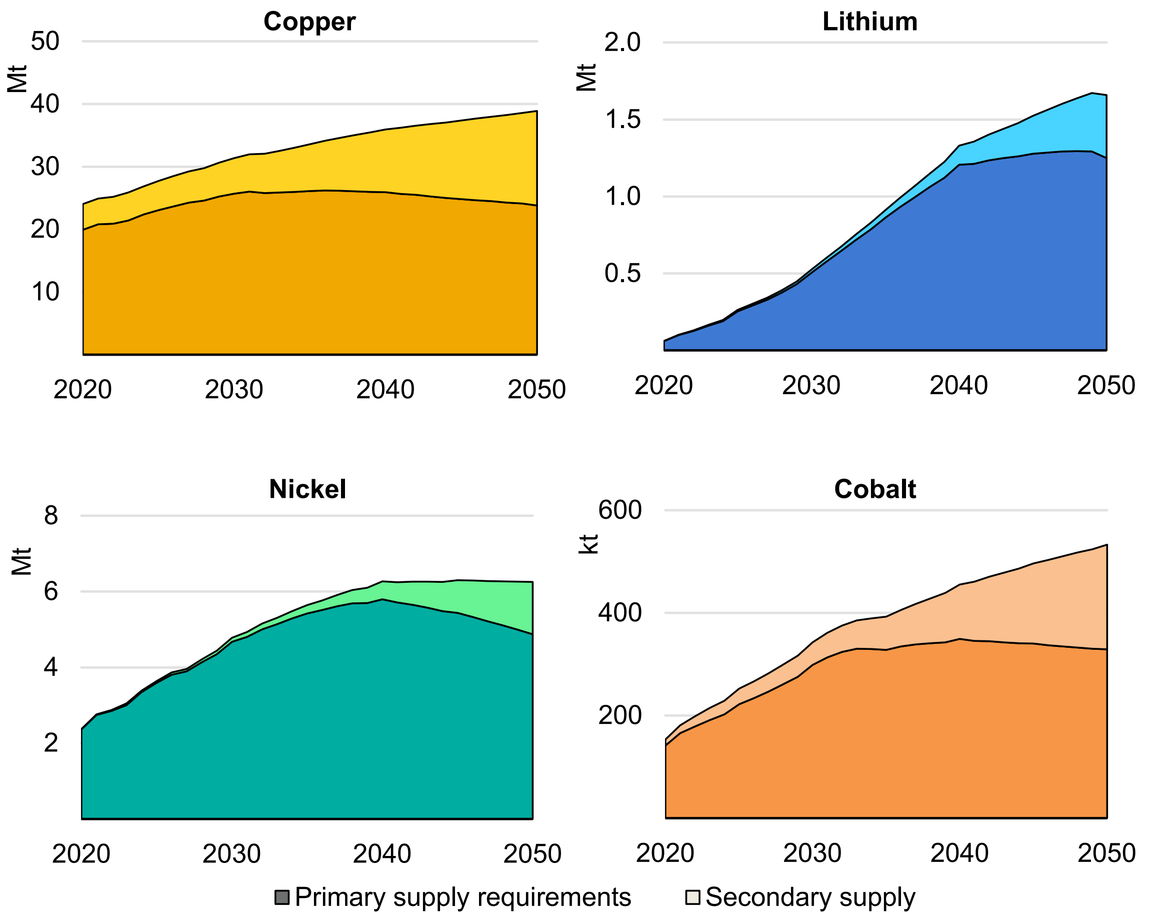


Notes: Available feedstock shows maximum possible feedstock volumes for recycling before any collection rates or recycling process yield losses are accounted for. A maximum utilisation rate of 85% for recycling capacity is assumed. Recycling capacity refers to material recovery capacity. Excludes batteries from portable electronics and e-bikes.
Source: IEA (2024), Recycling of Critical Minerals.

In the APS, the surge in recycling thanks to larger available feedstock and a higher collection rate of end-of-life batteries reduces lithium and nickel demand by about 25% and cobalt demand by about 40% by 2050. This improves the resilience of the battery materials supply chain, but does not preclude the need for large investments in new mines, both today and in the future, to satisfy growing battery demand and compensate natural production declines from older mines caused by lower ore quality or reduced profitability. This will bring significant investments in mining in EMDEs, which could also absorb more value added from the minerals they export by developing capacity for critical mineral processing, battery component and cell production and EV manufacturing.

Investments will also be needed to build recycling capacity in EMDEs other than China. This will be required to recycle manufacturing scraps in countries planning to become battery producers, and can also help address the issue of unregulated and untreated waste that might contain some critical or precious minerals alongside hazardous materials, such as from portable electronics and their batteries. Measures to prevent illegal waste export and import are the first step towards dealing with this issue, but collection and recycling rates also need to be increased in these regions, notably in Africa. To meet this aim, it will be crucial for advanced economies to support and invest in EMDEs to not only scale up recycling capacity, but also to promote technological transfer and local workforce training.

Primary supply requirements of key battery minerals with and without recycling in the Announced Pledges Scenario, 2020-2050



Notes: Primary supply requirements = total demand net of expected contributions from secondary supply and reuse. Primary supply requirements are calculated as "total demand net of secondary supply", also accounting for losses during refining operations. Lithium is defined on a lithium content basis. Includes total demand and secondary production from all sectors except for nickel, where secondary production from steel is excluded. Direct use scrap is excluded for copper.
Source: IEA (2024), Recycling of Critical Minerals.

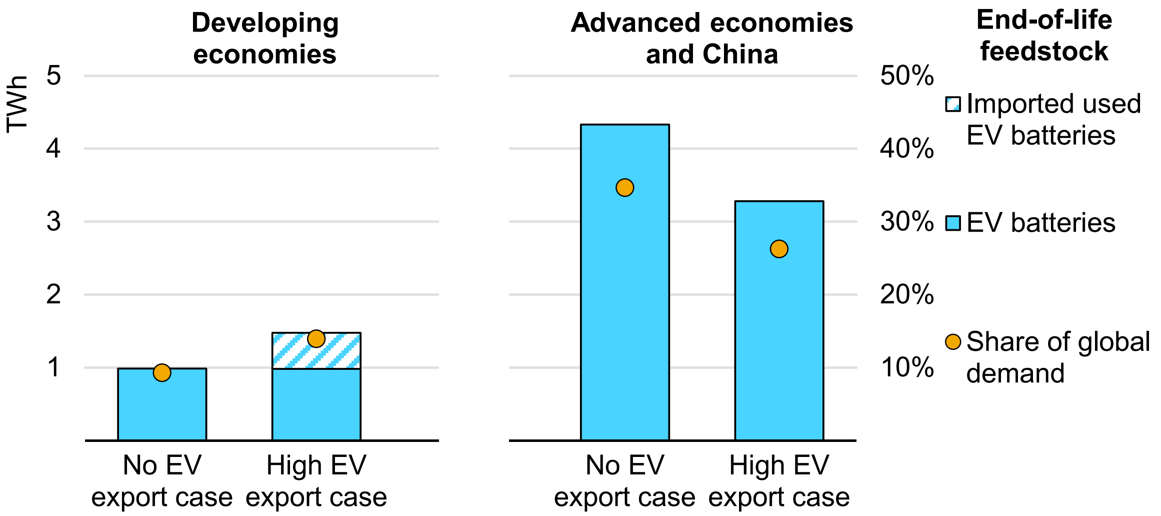
Impact of used EV exports on recycling

As the EV market matures, used electric cars will become more widely available, helping to increase affordability but also creating more uncertainties about the geographical distribution of retired batteries. In 2023, the market size for used electric cars was over 1.5 million vehicles, roughly equal to new electric car sales in the United States in the same year. China accounted for half of all global second-hand EV sales in 2023, and most of the rest were in the United States and Europe.

Second-hand markets are often the primary method for acquiring a car in both emerging and advanced economies, and a similar pattern is expected to emerge for EVs, helping to foster widespread adoption. However, regions lacking sufficient access to primary supplies of battery materials, such as Europe and

North America, might be inclined to keep second-hand EVs in the domestic market for longer to secure part of their critical minerals demand through recycling. This would reduce shipping of second-hand EVs to EMDEs, meaning that access to more affordable second-hand EVs could be delayed in those countries, which already account for only a small minority of the second-hand EV market. International trade of used electric cars also represents an opportunity for EMDEs other than China to develop servicing and industrial capacity to extend the lifetime of used EVs and to handle the batteries when they finally reach end of life. For example, assuming that second-hand EVs follow the same trade patterns as second-hand ICEVs today, the battery material available for recycling in EMDEs other than China would increase by 50% in 2050 in the APS.

Potential impact of used electric vehicles export on end-of-life battery feedstock for recycling, 2050



Notes: EV = electric vehicle. High export case assumes export of EVs is the same as for internal combustion engine (ICE) vehicles based on regional and country export share data. Demand refers to the Announced Pledges Scenario. No export case assumes there are no EV exports. Imported EV vehicles in developing economies are assumed to have a longer lifetime than those not traded in the international second-hand market, delaying their availability for recycling.
Source: IEA (2024), Recycling of Critical Minerals.

Policies to support battery sustainability and circularity

Current policies and initiatives

EU Batteries Regulation sets recycled content quota

The EU Batteries Regulation introduced in 2023 aims to reduce the carbon footprint of batteries, increase the number of batteries recycled, incentivise more sustainable battery designs and foster responsible materials sourcing. More specifically, it aims to ensure better traceability and recyclability through minimum performance standards and the introduction of labelling requirements, including QR codes and battery passports. The regulation also extends producer responsibility by reinforcing due diligence relating to social and environmental risks in the supply chains of critical raw materials used to manufacture batteries.

The regulation imposes minimum recycling efficiency (i.e. how many batteries, by mass, are recycled as a share of the total reaching end of life), which for lithium-ion batteries should be at least 65% by the end of 2025 and 70% by the end of 2030. Minimum material recovery efficiency (i.e. the share of recovered materials from a battery being recycled) varies among materials.

Minimum material recovery efficiency by material in the EU Batteries Regulation

	By 31st December 2027	By 31st December 2031
Cobalt	90%	95%
Copper	90%	95%
Lithium	50%	80%
Nickel	90%	95%

Note: Dates refer to the latest date at which the minimum shares should be achieved.
Source: EU Batteries Regulation.

Starting from 2031, the regulation sets the minimum quota of recycled materials that needs to be guaranteed in order for EV batteries to be sold in the European Union. This represents a strong incentive for the utilisation of recycled materials, and offers certainty for recycled materials markets, thereby decreasing the investment risks for recyclers. The main risk for this kind of target is the eventual lack of sufficient material feedstock for recycling, for example due to longer EV life than previously expected, or export of EVs through international second-hand markets – both of which are out of the control of battery manufacturers. If such a situation materialises, it would therefore create an advantage for battery manufacturers located in regions with the largest recycling feedstocks, with the largest of such markets expected to be China.

Minimum quota of recycled content by material in the EU Batteries Regulation

	18^{th} August 2031	18^{th} August 2036
Cobalt	16%	26%
Lithium	6%	12%
Nickel	6%	15%

Note: Dates refer to the dates from which the minimum shares should be applied.
Source: EU Batteries Regulation.

Global battery passport to address transparency

The global battery passport programme aims to define a global reporting framework for battery history and associated ESG performance across the battery supply chain. This digital passport would contain data and descriptions about battery manufacturing, provenance, and ESG performance over the entire supply chain, with the aim of enhancing transparency and facilitating the use of batteries in second-life applications (including second-hand EVs) and battery recycling. The programme plans to include in the passport different indicators, ranging from GHG emissions to environmental degradation such as biodiversity loss and water management, to human and workers' rights and impact on local communities.

The first pilot of the global battery passport was released in 2024, including ten case studies performed in collaboration with battery producers accounting for over 80% of today's battery market. The pilot considers seven different ESG standards and provides a score for each of them, when data is available, and gives a global ESG score. These pilots have been useful in identifying data gaps related to certain ESG metrics or certain steps of the supply chain that need to be addressed to improve the global battery passport programme.

Policy recommendations

Embrace a holistic approach

As governments develop industrial policies to support higher EV and battery demand and production, it will be important to factor in the infrastructural needs to support this transition and minimise any adverse effects. For example, an increase in domestic battery production also creates a need for recycling to deal with battery manufacturing scraps. Building battery recycling infrastructure in parallel with battery production can enable the reuse of manufacturing scraps, thereby minimising the environmental impact and bringing down the final production cost. This can also help to ready recycling facilities for when EV batteries reach end of life.

Decreasing the environmental impact of battery production will also require the utilisation of cleaner energy sources for the entire battery supply chain. Fully sustainable battery production will depend on greater electrification and a diminished electricity emissions intensity through larger shares of low-emissions energy sources. For EMDEs that largely use coal as a primary energy source, a shift towards cleaner energy sources should be a priority to decrease overall emissions and reduce local environmental and health hazards. In addition, in countries with critical mineral resources it will be crucial to minimise local environmental risks, such as water and air pollution and biodiversity loss associated with mining and refining, and to reduce the life cycle emissions of those minerals and therefore of the final batteries through use of cleaner energy sources.

Enhance transparency, traceability, and environmental, social and governance considerations

Employing traceability systems across the supply chain and tackling information gaps can be an important enabler of a more sustainable battery supply chain. Internationally recognised standards can ensure the credibility and robustness of the data collection and evaluation processes associated with traceability systems, and initiatives such as the global battery passport can offer the platforms needed for such systems.

Stronger transparency and traceability would benefit the entire supply chain, from countries producing or refining critical minerals, where higher ESG standards would be incentivised, to best-performing battery producers, who would see their efforts recognised, and finally to end consumers, facilitating responsible purchasing. Improved traceability is also important for battery recycling, which will be key to reducing critical mineral demand, especially from 2035. Similarly, battery traceability can also limit unofficial and unregulated battery recycling or reuse, such as EV battery cells dismantled for use in electric bikes. Creating certainty on the demand for recycled materials, such as through the EU Batteries Regulation, and increasing the collection rate are two areas in which policy makers have a large role to play. For example, thanks to dedicated regulations, lead-acid batteries are already collected and recycled at high rates in many countries today, despite having significantly lower residual value than end-of-life lithium-ion batteries.

Strengthen co-operation to facilitate second-hand EV trade

International trade of second-hand EVs represents an important opportunity for enhancing affordability and accelerating electric mobility in EMDEs other than China. Stronger co-operation between advanced economies and EMDEs could help facilitate trade in second-hand EVs while ensuring that end-of-life strategies are adequate. For example, there could be incentives or allowances associated with extended vehicle lifetimes through use in international second-hand markets, as long as recycling in the destination market is guaranteed, or the EV battery is returned at its end of life. An alternative form of co-operation could be locally pre-treating end-of-life batteries, which requires less capital-intensive facilities, and sending back the black mass thereby obtained to the region where the EV was originally registered for the final material recovery step. Harmonising international classification and establishing detailed yet practical criteria for classifying lithium-ion battery waste and black mass would help reduce trade barriers and create a larger market for recycling. Measures to prevent unofficial recycling and illegal exports and imports of material wastes, with their associated environmental and health hazards, will also be important to ensure the sustainability of recycling and international trade of second-hand EVs.

Annex

Abbreviations and acronyms

APS	Announced Pledges Scenario
BEV	battery electric vehicle
EMDE	emerging markets and developing economies
ESG	environmental, social and governance
EV	electric vehicle
FTA	free trade agreements
GHG	greenhouse gas
HEV	hybrid electric vehicle
ICEV	internal combustion engine vehicles
ICE	internal combustion engine
LFP	lithium iron phosphate
NMC	lithium nickel cobalt manganese oxide
NZE	Net Zero Emissions by 2050 Scenario
PHEV	plug-in hybrid electric vehicle
STEPS	Stated Policies Scenario
2/3-wheelers	two- and three-wheelers

Glossary

GWh	gigawatt hour
GWh/yr	gigawatt hour per year
kg CO_2-eq	kilogramme of carbon dioxide equivalent
kt	kilotonnes
kWh	kilowatt hour
Mt	megatonnes
t CO_2-eq	tonne of carbon dioxide equivalent
TWh	terawatt hour
TWh/yr	terawatt hour per year

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