Minimizing Mining Impacts on the Road to Zero Emissions Transport

Prepared for Earthworks

Institute for Sustainable Futures

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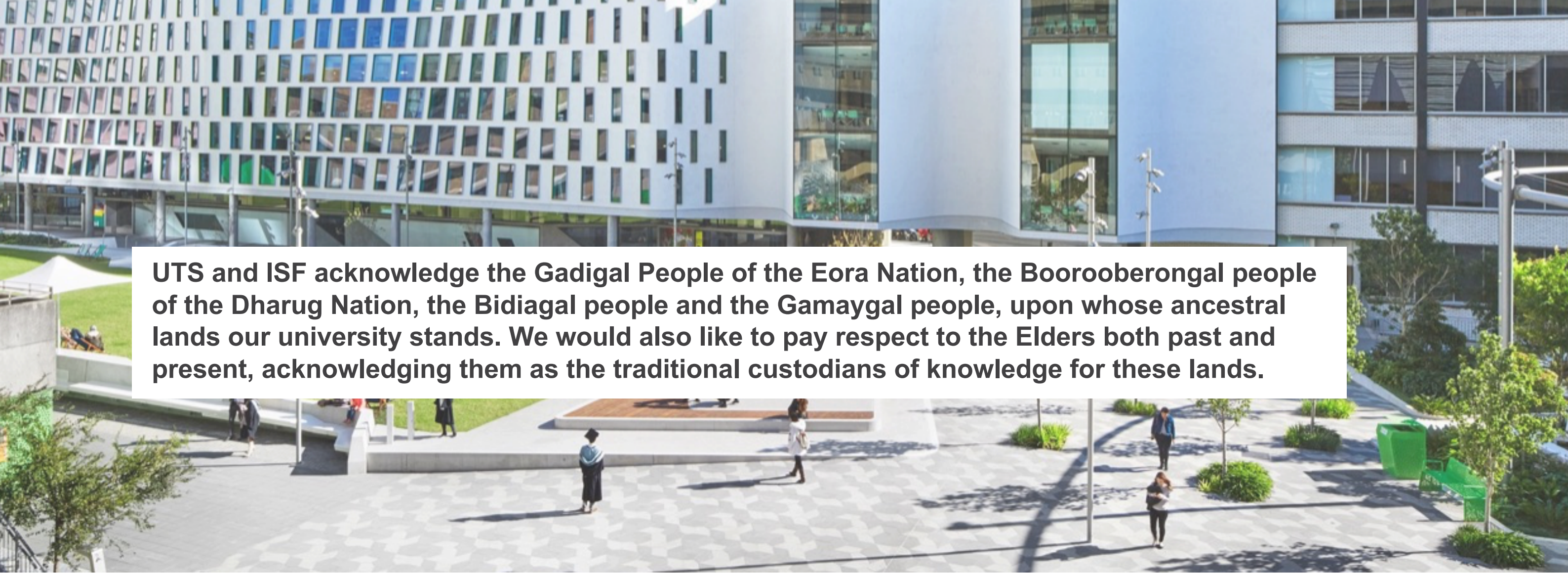

UTS and ISF acknowledge the Gadigal People of the Eora Nation, the Boorooberongal people of the Dharug Nation, the Bidiagal people and the Gamaygal people, upon whose ancestral lands our university stands. We would also like to pay respect to the Elders both past and present, acknowledging them as the traditional custodians of knowledge for these lands.

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About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures. We utilise a unique combination of skills and perspectives to offer long term sustainable solutions that protect and enhance the environment, human wellbeing and social equity.

About Earthworks

Earthworks is a nonprofit organization dedicated to protecting communities and the environment from the adverse impacts of mineral and energy development while promoting sustainable solutions. We work with communities and grassroots groups to reform government policies, improve corporate practices, influence investment decisions, and encourage responsible materials sourcing and consumption. We expose the health, environmental, economic, social, and cultural impacts of mining and energy extraction through work informed by sound science.

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Executive Summary

To prevent the worst effects of climate change, countries must swiftly move away from fossil fuel-based energy and transportation systems. Reducing emissions in the transport sector, which makes up 20% of global emissions, is crucial. Within the sector, road transportation – specifically passenger vehicles including cars, motorcycles, buses and taxis – are responsible for the largest share of emissions.[1]

In most countries, solutions to decarbonizing road passenger transportation rely predominantly on the electrification of existing transport modes. In the Global North, replacing private internal combustion energy vehicles (ICEVs) with private electric vehicles (EVs) is promoted as the primary solution.

EVs are an important part of decarbonizing road transportation. But the rising demand for lithium-ion batteries (LIBs) for EVs is increasing the demand for minerals such as cobalt, copper, graphite, lithium, manganese and nickel. LIBs make up a large portion of the mineral demand, and greenhouse gas (GHG) emissions, from an EV.[2] They also contain minerals for which demand is rapidly increasing, raising concerns over associated human rights and environmental impacts.[3]

Relying only on a transition to EVs to decarbonize road passenger transport, without considering how to minimize mineral demand and mining impacts, will lead to further inequitable distribution of benefits and adverse impacts for communities and ecosystems across the globe. There are already many documented impacts from mining for EV supply chains, including in Chile, the Democratic Republic of Congo, Indonesia, the United States (US), the Philippines and Russia.[4]

To ensure the transition to renewable energy and transport systems is socially just and ecologically sustainable, it is important to address the human rights and environmental impacts associated with sourcing minerals for the energy transition. It is essential that solutions for decarbonization minimize the amount of mining required, and when mining is required, it must be done as responsibly as possible.

The case studies in this report demonstrate that solutions for decarbonization that minimize new mining are not only possible, but well under way, in a wide range of geographies and scenarios. Effective policy measures and political will would allow us to scale up these measures and deliver far-reaching, comprehensive results to meet our climate and decarbonization goals without the adverse impacts caused by new mining.

Scope and objectives

While the impacts of mining related to the energy transition and EVs are becoming more widely understood, there is little research to understand what can be done to reduce these impacts. The aim of this research project is to identify and evaluate the most important strategies to avoid and minimize the mining impacts associated with EVs, while moving away from a fossil fuel-based transport system. This includes strategies to reduce the demand for mining, by reducing the total demand for minerals and the demand for primary minerals, and strategies to minimize harms from mining when it occurs.

[1] Ritchie, H. (2020, October 6). *Cars, planes, trains: where do CO2 emissions from transport come from?* Our World in Data. https://ourworldindata.org/co2-emissions-from-transport
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[3] Dominish, E., Florin, N. and Teske, S., (2019). *Responsible Minerals Sourcing for Renewable Energy.* Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. https://earthworks.org/wp-content/uploads/2019/04/Responsible-minerals-sourcing-for-renewable-energy-MCEC_UTS_Earthworks-Report.pdf
[4] Ibid

Key findings

1. A large increase in the adverse mining impacts from EVs is avoidable.

- There are many pathways to transition from our current fossil-fuel based road transport systems towards zero emissions systems. This can be done by prioritizing solutions for decarbonizing that minimize the high mineral demand of EVs and mitigate the adverse mining impacts.
- These solutions are proven, and in many cases readily available, and are already being successfully implemented by cities, countries and industries across the globe.

2. Reducing car dependence and shifting towards smaller EVs and batteries are the most impactful strategies to swiftly reduce mineral demand for EVs.

- Reducing car dependence, through urban redesign and improving active and public transport, reduces the total demand for minerals in the transition as fewer EVs will be required on the road. Smaller EVs require much smaller batteries than larger vehicles.
- Closing the loop on battery materials through enhanced recycling will play an important role in reducing primary mineral demand from the mid-2030s, once substantial volumes of LIBs from EVs reach end-of-life.
- Extending the lifespan of vehicles and batteries, particularly through repurposing into applications such as stationary storage, can also reduce the demand for minerals, but to a smaller degree than other strategies.

3. Strategies that reduce mineral demand for EVs will also help meet climate goals in the transport sector.

- Only relying on EVs, without reducing private car use, will not reduce emissions fast enough. Reducing car dependence can make a quicker, larger and more cost-effective reduction in emissions compared to electrification of vehicles alone.
- Smaller-sized EVs can speed up the decarbonization of road transport as they are more affordable and have lower emissions from manufacturing.

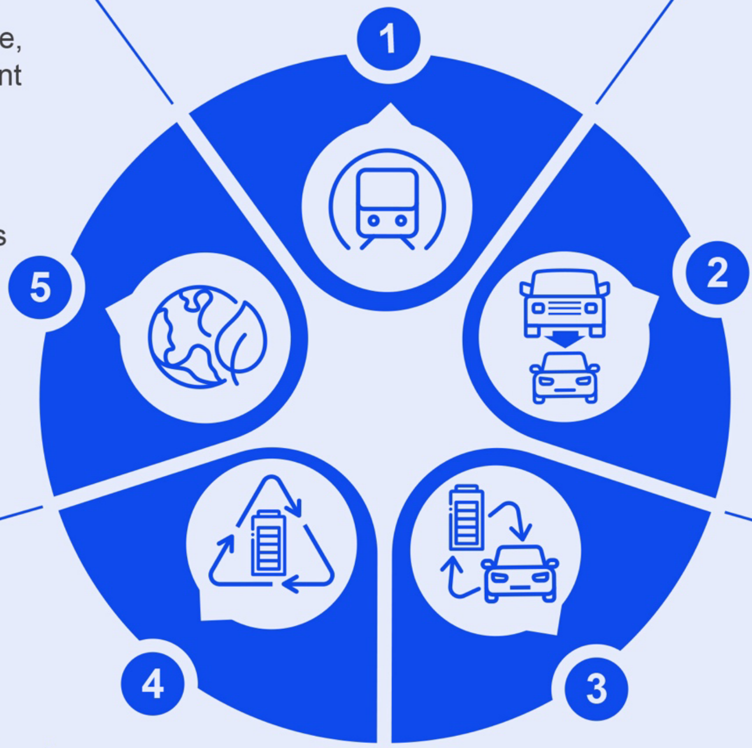
4. Strategies that reduce mineral demand can also improve social equity.

- For example: improving, expanding and electrifying public and active transportation can spread the benefits of low emission transport to more people, and lead to other benefits such as improvements in air quality, liveability, public health and wellbeing.

5. There is an urgent need for more responsible mining practices that respect human rights and protect the environment.

- Current practices often create unsafe conditions for communities near mines, mine workers, and the environment. There are many examples of the mining industry violating the rights of Indigenous Peoples and invading their lands and territories. This cannot be allowed to continue.

Key principles to minimize the mining impacts of EVs



Reduce car dependence

- Redesign cities to minimize the need to travel
- Shift from private vehicle use to public transportation, walking and cycling

Shift to smaller and more efficient vehicles and batteries

- Smaller sized vehicles
- Efficient battery design and manufacturing

Use vehicles and batteries more intensively over their lifespan

- Remanufacturing and repurposing EV batteries at end-of-life
- Reuse of second-hand EVs
- Expanding sharing to EVs
- Battery leasing and swapping

Close the loop on battery minerals

- High recovery rates of minerals from battery recycling
- Advanced recycling that meets rigorous environmental and labor standards

Source minerals more responsibly

- Guarantee the right to Free, Prior and Informed Consent (FPIC) and uphold the rights of Indigenous Peoples
- Supply chain human rights and environmental due diligence (HREDD)
- Adherence to rigorous regulations and standards to protect communities and ecosystems

PRINCIPLE 1:

Reduce car dependence

Reducing car dependency, so that everyday travel is not reliant on private car use without reducing living standards, can be achieved by redesigning cities to reduce the need to travel, and by shifting from private cars to other, more efficient, transport modes such as public transportation, walking and cycling. This can be implemented through a range of policies and programs including the integration of transport and urban planning, infrastructure investment and financial incentives. It is important to note that many cities have only become car dependent in the last few decades because of direct policies to encourage car use, and many cities known for their good public transportation systems were previously highly car dependent and were able to implement changes to reduce car dependency relatively quickly.

Decarbonizing road passenger transportation will require systemic changes and significant investment whether this is achieved by shifting towards EVs, public and active transport or both. Although challenging, reducing car dependence has the added benefit of being able to improve transport systems to better meet societal needs, improve liveability, and increase equity and wellbeing.

PRINCIPLE 2:

Shift to smaller and more efficient vehicles and batteries

Smaller-sized EVs require much smaller batteries than their larger counterparts, which can have batteries two or three times the size of smaller vehicles' batteries. Modeling has found that limiting the battery size of vehicles could reduce the annual demand for lithium in the US in 2050 by 42%. However, this would require reversing the global trend towards SUVs and larger vehicles. Smaller EVs are also more efficient (they use less electricity to travel the same distance), have lower emissions from manufacturing, are more affordable, and are safer for pedestrians and cyclists in accidents.

The auto industry is making significant progress towards increasing the efficiency of battery design, so that smaller amounts of minerals are required to manufacture a battery that can store the same amount of energy. However, the low rates of recycled content used in battery manufacturing could be improved to reduce demand for primary minerals, which would also significantly reduce the embedded GHG emissions of an EV. Shifts in battery chemistries or to new battery technologies can reduce demand for specific metals, such as cobalt, but may not lead to a net reduction in overall mineral requirements. The benefits of improving the efficiency of the battery design and manufacturing will be offset if batteries are used in large EVs.

PRINCIPLE 3:

Use vehicles and batteries more intensively over their lifespan

Using EVs and batteries more intensively over their lifespan can reduce the demand for new mining, as it can reduce the number of new EVs and batteries needed to meet the same requirements. For EVs, this can be done by EV sharing and by reuse of second-hand EVs after their first life. For batteries, this can be done by battery sharing through battery leasing and swapping schemes, by remanufacturing of end-of-life EV batteries so they can continue to be used in EVs and by repurposing of end-of-life EV batteries into other uses, such as stationary energy storage.

Most EV batteries will be suitable for remanufacturing or repurposing when they reach end-of-life. Modeling of reuse of EV batteries for replacement or repurposing for stationary energy storage found that mineral demand could be reduced by 18% by 2050. However, the stationary storage market is much smaller than the

EV market and eventually batteries that are suitable for repurposing will need to be recycled once demand for stationary storage has been met. Remanufacturing of EV batteries for use again in EVs is an emerging idea, however, it will likely only meet a small percentage of battery demand each year. Both these strategies will require batteries to be designed so they are durable, repairable, and can be easily, safely and economically handled.

The extent to which sharing of EVs can reduce mineral demand is unknown. Car sharing is likely to have a positive benefit by reducing vehicle ownership, but ride-sourcing and ride-hailing apps are likely to encourage additional trips and shift away from public transportation, which could therefore lead to a net increase in new vehicles. Sharing of batteries through battery leasing and swapping programs could encourage the use of smaller batteries, increase battery lifespan through maintenance and repair, and increase the likelihood of reuse and recycling at end-of-life.

PRINCIPLE 4:

Close the loop on battery minerals

Recycling can reduce the demand for new mining as it creates a supply of recycled metals that can be used for new battery manufacturing. Modeling of EV mineral demand has shown that recycling can significantly decrease primary mineral demand by 25-55% in 2040, and cumulative demand by 2050 by 23-44%. However, this impact will be minimal over the next decade and then gradually have a greater impact once large volumes of LIBs from EVs reach end-of-life.

Investment is required early on to make sure appropriate collection systems and infrastructure are in place once batteries reach end-of-life, and that recycling processes have high recovery rates of metals, not just those that are more valuable. Design for circularity is needed for batteries entering the market now so they can be easily, safely and affordably processed when they reach end-of-life.

PRINCIPLE 5:

Source minerals more responsibly

There is an urgent need for more responsible sourcing practices to avoid and minimize the risk of adverse social and environmental impacts of mining for EVs. Critical to this is guaranteeing the right of Free, Prior, and Informed Consent (FPIC) for Indigenous Peoples and their right to self-determination for any activities undertaken on their land. However, this practice is usually poorly implemented and in most cases is defined by private companies rather than Indigenous Peoples and is not enforceable under national laws. Human rights and environmental due diligence (HREDD) policies are also crucial for companies to identify and address social and environmental risks in EV supply chains.

Other important practices include adhering to rigorous regulations and standards, such as the Initiative for Responsible Mining Assurance (IRMA); paying a living wage and ensuring the rights and safety of workers in industrial mines; improving environmental monitoring and compliance at mine sites; establishing 'No-go zones' or moratoriums on mining in critical ecosystems and sacred places; and ensuring there are no reprisals, attacks or criminalization of human rights and environmental defenders, many of whom are Indigenous Peoples and/or women.

These strategies can help ensure the production of EVs to meet climate goals does not have the unintended effect of burdening communities, regions and ecosystems, many of which will be most impacted by climate change.

Glossary & Acronyms

BMS	Battery management system
BRT	Bus Rapid Transit
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric vehicle
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt hours
GPI	Global Procurement Initiative
HREDD	Human Rights and Environmental Due Diligence
IEA	International Energy Agency
IEC	International Electrochemical Commission
ILO	International Labour Organisation
LEV	Low-emission vehicle
LEZ	Low-emission zone
LFP	Lithium iron phosphate (type of LIB)
LIB	Lithium-ion battery
LNMO	Lithium nickel manganese oxide (type of LIB)
LTZ	Limited traffic zone
LMT	Light means of transport
NMC	Nickel manganese cobalt (type of LIB)
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PFAS	Per- and polyfluoroalkyl substances
PHEV	Plug-in hybrid electric vehicle
PLDV	Passenger light duty vehicle
SOH	State of health
SME	Small and medium-sized enterprises
SUV	Sports Utility Vehicle
TOD	Transit-oriented development
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
PV	Photovoltaic
ZEV	Zero-emission vehicle
ZEZ	Zero-emission zone

Contents

Introduction

The transport sector accounts for around 20% of global greenhouse gas (GHG) emissions, and the largest share of this, approximately 9% of global emissions, is from road passenger vehicles, including cars, buses, motorcycles and taxis.[5] Emissions from the transport sector have grown faster than any other end-use sector, growing at an annual average rate of nearly 1.7% from 1990 to 2021.[6]

The need to decarbonize the transport system is clear and the timeframe for achieving zero emissions is narrowing. Efforts to reduce emissions in the road transport sector are focused on the adoption of electric vehicles (EVs), as reducing emissions from passenger vehicles faces fewer technological barriers than other parts of the transport sector, such as heavy trucks, shipping and aviation.[7] A growing number of countries have committed to phase out internal combustion engine vehicles (ICEVs) or have set targets for the electrification of vehicles in the next 10 years.[8] However, these efforts alone are insufficient to meet climate targets in the transport sector, which will also require systemic changes in infrastructure, urban form, technology and behaviors.[9]

A socially just and ecologically sustainable transition to zero emissions energy and transport systems is essential to ensure the transition does not create unintended harm. As they tackle the climate crisis, many countries have adopted the aim of a 'just transition' to ensure the climate and energy transition happens in a fair and inclusive way. This means supporting countries and communities affected by the costs of the transition and sharing of the benefits.[10] For a truly just and equitable energy transition, it is important to consider the impacts of the introduction of renewable energy and transport technology and infrastructure on communities along the entire supply chain – from the extraction of minerals, to their use, and at end-of-life.[11]

Demand is growing rapidly for minerals for the energy transition – known as 'transition minerals' – such as cobalt, copper, graphite, lithium, manganese, and nickel. Lithium-ion batteries (LIBs) for EVs are the major driver of this demand, projected to account for half of the minerals required for a transition to renewable energy and transport systems.[12] Demand increases from EV supply chains is exacerbating the existing adverse human rights and environmental impacts of the mining sector. There is a specific risk of increased harm emerging in these supply chains because of the rapid growth in demand and the geographic location of these minerals.

Several of these transition minerals, such as cobalt and lithium, have only previously been mined in small amounts, and demand from EVs is increasingly being cited as a reason for new mining projects. These minerals are commonly found in environmentally sensitive and often economically marginalised regions of the world. Increased mining has the potential to lead to harmful impacts on local environments, including soil, air, and water pollution; and to human rights impacts for workers and local communities, in particular Indigenous Peoples.[13]

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[5] Ritchie, H. (2020, October 6). *Cars, planes, trains: where do CO2 emissions from transport come from?* Our World in Data. https://ourworldindata.org/co2-emissions-from-transport
[6] International Energy Agency. (2022). *Transport Tracking Report 2022.* https://www.iea.org/reports/transport
[7] International Energy Agency. (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector.* https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf
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[9] Jaramillo, P., S. Kahn Ribeiro, P. Newman, S. Dhar, O.E. Diemuodeke, T. Kajino, D.S. Lee, S.B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead. (2022). Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.
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Examples of impacts from EV mineral supply chains include:

- More than 70% of the world's cobalt is mined in the Democratic Republic of Congo (DR Congo). The majority of this is from large industrial mines where Congolese workers face violence, racism and unsafe working conditions. Many workers are paid as subcontractors, earning as little as US $2.50 a day, well below the living wage.[14] An estimated 200,000 people work in unsafe informal mines, and there have been hundreds of deaths and injuries from mine collapses.[15]
- Indonesia and the Philippines are major producers of nickel-ore for EV batteries. In Indonesia, which has half of the global nickel reserves, mining has ramped up with more than US $14 billion of international investment over the past decade.[16] Most of this mining is concentrated in Sulawesi, where mining has led to increased deforestation, and contaminated soil from the mines has destroyed crops and polluted the ocean, creating risks for fishing.[17] Communities have also faced forced evictions from customary lands, loss of income, air pollution from smelters, and contaminated public water supply.[18] In the Philippines, nickel mining is causing similar harms; for example, unsafe levels of carcinogenic heavy metal hexavalent chromium have been found in rivers downstream of nickel mining.[19] There are ongoing conflicts as communities on islands in Palawan and Sibuyan resist nickel mining operations.[20]
- Nickel mining activities in Russia by Nornickel, the largest global nickel producer, has led to destructive environmental and economic impacts to Indigenous communities including the Sámi, Nentsy, Nganasan, Entsy, Dolgan, and Evenki communities. A large oil spill in May 2020 polluted rivers surrounding the Ust-Avan indigenous village on the Taimyr Peninsula in the Russian Arctic. Residents can no longer rely on traditional fisheries for food, have not received compensation and have faced reprisals for speaking out about the violations of their rights.[21]
- More than half of the world's reserves of lithium are found underneath the desert salt flats on the borders of Argentina, Bolivia and Chile. In this region, lithium is extracted by pumping brine to the surface, which uses vast amounts of water – roughly 2 million litres of water per tonne of lithium – risking damaging the unique desert ecosystem and wetlands. In Chile's Atacama Desert this has led to extreme water shortages and water pollution, particularly impacting Indigenous communities.[22]
- Australia is the largest lithium producer in the world and is rapidly escalating investment in other minerals including cobalt, nickel and copper. Further expansion of mining will put more strain on already damaged ecosystems, and land rights regulations are insufficient to protect Indigenous and local communities.[23]
- In the United States, a lithium mine at Thacker Pass, Nevada began construction in early 2023, without consent from affected Indigenous communities. Communities are continuing to protest the project, concerned about the environmental impacts and the destruction of an important sacred site, which was also the site of a massacre of Native Americans in 1865.[24]

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[14] RAID and CAJJ. (2021). *The Road to Ruin? Electric vehicles and workers' rights abuses at DR Congo's industrial cobalt mines.* https://www.raid-uk.org/sites/default/files/report_road_to_ruin_evs_cobalt_workers_nov_2021.pdf

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- Deep sea mining has been proposed to extract cobalt and manganese from the seabed. However, there are significant environmental risks and uncertainties, including loss of biodiversity and destruction of fragile ecosystems with sediment from disruption of the sea floor, waste discharge and noise pollution.[25] Communities in the Pacific are concerned about the impact on their fisheries and livelihoods.

In addition to the mining impacts of EVs, there are other challenges to their adoption. In many parts of the world, the high cost of EVs has limited their adoption, which may increase inequality. Additionally, public subsidies are disproportionately benefiting wealthier households, who are more likely to be able to afford new EVs.

When LIBs from EVs reach end-of-life they pose potentially significant environmental, health, and safety risks. It is forecasted that by 2030, there will be a global volume of approximately 1.7 million tonnes of end-of-life batteries and production scrap, a 250% increase compared to 2021.[26] If not safely managed, end-of-life LIBs may overheat or catch fire.[27] If recycling is not undertaken responsibly, there can be adverse health effects for workers and environmental pollution.[28]

EVs are an important part of decarbonizing passenger road transportation. But EVs are mineral intensive – LIBs for EVs use several hundred kilograms of minerals that are almost exclusively sourced from primary sources. If we rely on EVs as the major solution to decarbonize passenger road transportation without considering how to minimize mineral demand and mining impacts, this could lead to large amounts of new mining and potential adverse impacts.

To ensure the transition towards zero-emission energy and transport systems is socially just and ecologically sustainable, it is important to address the adverse human rights and environmental impacts associated with sourcing minerals for EVs. It is essential that solutions for decarbonization minimize the amount of mining required, and when mining is required, it must be done as responsibly as possible.

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Report scope and objectives

The aim of this research project is to identify and evaluate the most important strategies to avoid and minimize the mining impacts associated with EVs and LIBs. This includes strategies to reduce the demand for mining, by reducing the total demand for minerals and the demand for primary minerals and strategies to minimize harms from mining.

The scope of this report has been selected as i) road passenger vehicles are responsible for a high share of GHG emissions and EVs have been the most widely adopted solution to reduce emissions in this sector ii) EVs and associated LIBs are projected to have the highest mineral demand of all the technologies required for the energy transition, as well as contain minerals for which demand is rapidly increasing demand raising concerns over associated human rights and environmental impacts.

While the impacts of mining related to the energy transition and EVs become more widely understood, there is very little research to understand what can be done to reduce these impacts. This report seeks to provide an overview of the opportunities to minimize these impacts and share examples of solutions. The objectives of this study are to:

- identify the key strategies to reduce mineral demand and the demand for new mining for EVs and LIBs;
- evaluate the potential of strategies to reduce mineral demand, their current level of implementation, the co-benefits and risks, and the barriers and enablers to increasing uptake;
- identify the key responsible sourcing practices;
- highlight credible examples of how these strategies can be achieved and scaled-up.

The scope is focused on strategies for two broad groups:

- consumer-facing companies (such as EV manufacturers and retailers), as they are large purchasers of raw materials, and are an important leverage point to drive change higher up the supply chain;
- governments, as they are large purchasers of technologies, and can drive change in their suppliers through more circular and responsible procurement practices.

Approach

The methodology for this report consisted of a literature review, stakeholder engagement and expert interviews. Interviews were undertaken with the following stakeholders:

Interviewee	Organisation
Zoe Allen	Zero Emission Vehicle Manager, C-40 Cities
Jessie Cato	Natural Resources & Human Rights Programme Manager, Business and Human Rights Research Center
Kate Finn	Executive Director, First Peoples Worldwide, University of Colorado
Cecilia Mattea	Clean Vehicles Officer, Transport and Environment
Ian Morse	Independent Mining Journalist
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Key findings

The mining impacts associated with EVs can be dramatically reduced by implementing strategies to reduce the demand for mining, reduce the total demand for minerals, and minimize harms from mining. We have identified five key principles for reducing the mining impacts of EVs, as shown in Figure 1.

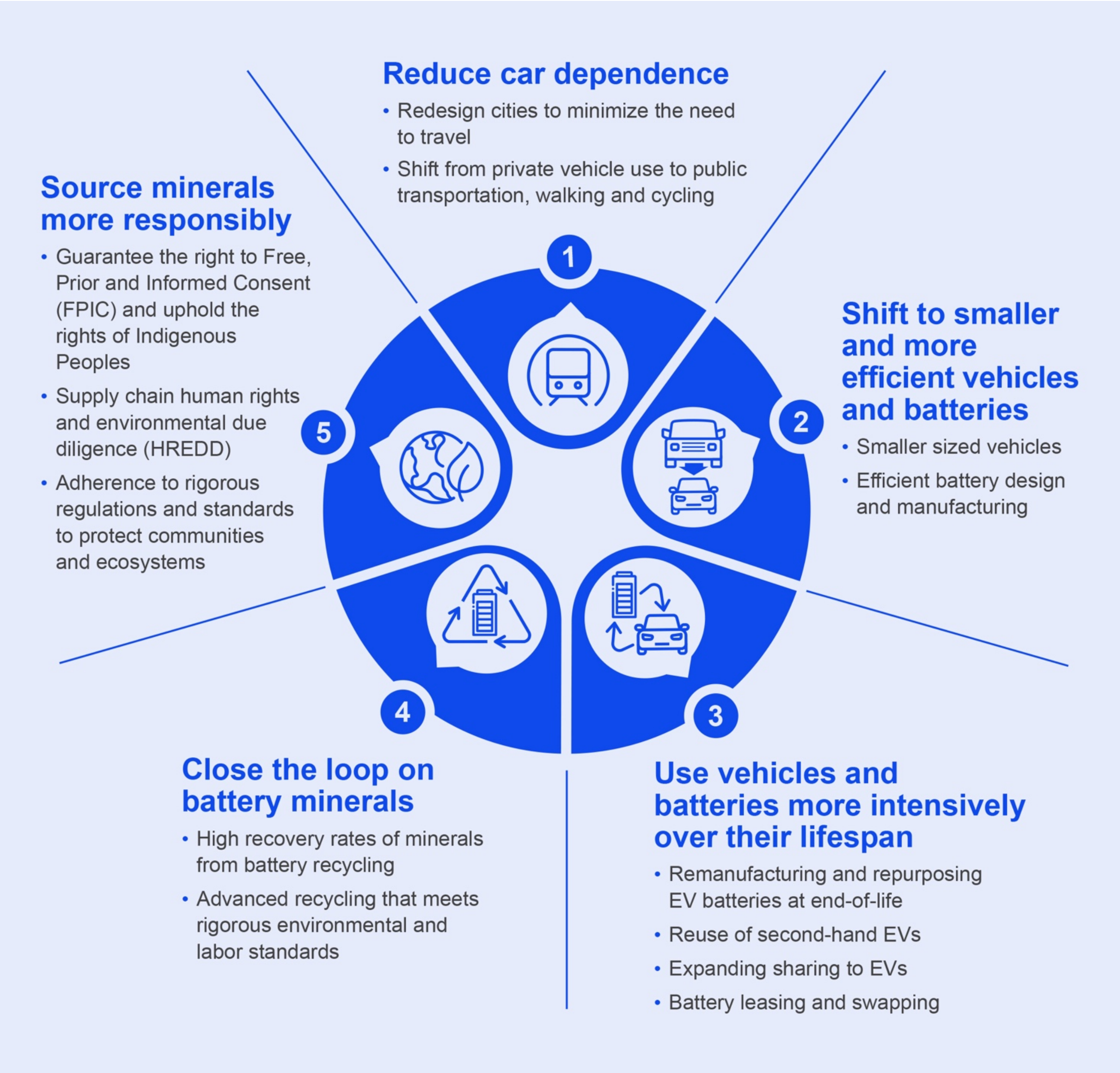

Figure 1: Key principles to minimize the mining impacts of EVs

Reducing car dependency and a shift towards **smaller EVs and batteries** are the most impactful strategies to reduce the negative impacts of mining for EVs, as they can swiftly and significantly reduce the total demand for minerals. Reducing car dependency, so that everyday travel is not reliant on private car use, can be achieved by redesigning cities to reduce the need to travel and shifting from private cars to other more efficient modes of transport such as public transportation, walking and cycling. This can reduce mineral requirements as: a) fewer EVs will be required to meet transport needs, and b) active and public transportation modes account for less minerals per person than private EVs. The size of EVs and batteries, and therefore the mineral demand, varies widely, with smaller EVs requiring much smaller batteries than a larger vehicle. There is a need to reverse the global trend towards SUVs and larger vehicles, which require larger batteries to travel the same distance as smaller vehicles, and often have batteries far larger than is needed for how they are used.

Closing the loop on battery materials will play an important role in reducing primary mineral demand from the mid-2030s. Recycling will gradually have a positive impact as more LIBs from EVs reach end-of-life and the recovered metals can be used for new battery manufacturing. Recycling technologies such as direct recycling and advanced hydrometallurgical processes, which recover almost 100% of materials, will have the biggest impact on reducing demand. Repurposing end-of-life EV batteries for stationary storage can also significantly reduce the demand for minerals in the short term, until demand is met from the stationary storage market, which is much smaller than that of EVs. Strategies for sharing vehicles, particularly car sharing, could also have an impact although this is uncertain, and ride-sourcing could in fact lead to increased car use and emissions. Battery leasing and sharing is a new model that uses the battery as efficiently as possible and enables reuse and recycling at end-of-life.

There is an urgent need for more responsible sourcing practices that respect human rights and protect the environment. This includes ensuring Free, Prior and Informed Consent (FPIC),[29] undertaking supply chain human rights and environmental due diligence (HREDD), adhering to rigorous voluntary standards in the absence of laws and regulations, ensuring the rights and safety of workers in industrial mines, paying a living wage, improving environmental standards at mine sites, establishing 'no-go zones' or moratoriums on mining in critical ecosystems and no reprisals or attacks on human rights and environmental defenders.

Strategies that reduce mineral demand for EVs will also help meet climate goals in the transport sector. To reduce emissions in the road transport sector in line with limiting global warming to 1.5-2°C, it is necessary to pursue a combination of strategies to transition away from ICEVs. EVs will play a crucial role in reducing emissions; however, the replacement of ICEVs with EVs alone may not meet climate targets unless there is a large reduction in the number of vehicles.[30]

Reducing car dependence can make a quicker, larger and more cost-effective reduction in emissions compared to electrification of vehicles alone. Even a modest reduction in the number of private passenger vehicles will have a significant impact on reducing emissions. This has benefits for reducing emissions in multiple ways: by minimizing the use of existing ICEVs; by shifting to active and public transportation which have lower GHG emissions per passenger; and because fewer EVs will be required to electrify all passenger vehicles, as well as less charging, energy generation and transmission infrastructure. Widespread adoption of strategies to reduce car dependency would reduce emissions more swiftly than relying on the replacement of the ICEVs with EVs, and the earlier emissions reductions are achieved, the greater the climate benefit.[31]

Smaller sized vehicles and batteries can also speed up the decarbonization of the road passenger transport system as they are more affordable and have lower emissions from manufacturing. Although the lifespan GHG emissions of an EV are lower than those of ICEVs, EVs have high GHG from their manufacturing, most of which is from the LIB.[32] The emissions from EV production can first be reduced by reducing vehicle and therefore battery size, as a large EV can have a battery two to three times larger than a small EV.[33] Electric micromobility (e-bikes, standing scooters), two-wheelers (scooters, motorbikes) and three-wheelers (rickshaws) all require much smaller batteries. Emissions can also be reduced by using recycled battery materials, which typically have a carbon footprint a quarter of the size of the emissions from raw materials from primary sources.[34] If vehicle and battery sizes continue to increase, this could erode some of the GHG emission benefits of transitioning to EVs.[35]

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[29] FPIC is a right that Indigenous Peoples have to self-determine what activities will or will not take place on their territories. It is enshrined in the UN Declaration on the Rights of Indigenous Peoples and in ILO 169. It is the right to approve, reject, or approve with conditions any proposed projects on their lands and territories, or that will impact their community.

[30] Alarfaj, A. F., Griffin, W. M., & Samaras, C. (2020). Decarbonizing US passenger vehicle transport under electrification and automation uncertainty has a travel budget. *Environmental Research Letters*, 15(9), 0940c2.

[31] Winkler, L., Pearce, D., Nelson, J., & Babacan, O. (2023). The effect of sustainable mobility transition policies on cumulative urban transport emissions and energy demand. *Nature Communications*, 14(1), 2357.

[32] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries

[33] Lopez, F. A., Billy, R. G., & Müller, D. B. (2023). Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles using the global MATILDA model. *Resources, Conservation and Recycling*, *193*, 106951.

[34] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries.* https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries

[35] International Energy Agency. (2022). *Global EV Outlook 2022.* https://www.iea.org/reports/global-ev-outlook-2022.

Strategies to reduce mineral demand can improve social equity in the transition. At a global level, wealthier countries are responsible for the majority of historic GHG emissions from road passenger transportation. Even as they adopt EVs, these countries will continue to contribute a disproportionately high level of emissions compared to countries that favour public transport or micromobility. It is primarily wealthier countries that will benefit from the co-benefits of EVs, such as cleaner air and lower running costs, as the high costs of EVs mean they are not available or affordable in many countries. EVs are also not accessible to large parts of society within wealthier countries, and subsidies to encourage EV uptake will disproportionately benefit higher income households and neighbourhoods. Improving, expanding and electrifying public and active transportation can spread the benefits of low-emission transport to a wider group of the population, and lead to other benefits such as improvements in air quality, amenities, public health and wellbeing.[36] Car sharing schemes can increase the equity of access to EVs, and there are examples where the schemes have been designed to directly support low-income neighbourhoods. Smaller vehicles and battery leasing schemes can increase the access to EVs by providing more affordable options. Safety is an additional benefit from reduced car use and from smaller vehicles, which are less dangerous to pedestrians and cyclists.

Adverse mining impacts and high mineral demand from EVs are not inevitable outcomes. There are many pathways to transition the road passenger transport sector to zero emissions, and it can be done in a way that minimizes mineral demand and mining impacts. In some cases, the trends are heading in the wrong direction – car use is projected to grow, vehicles are getting larger and there are low LIB recycling rates. However, these trends are not inevitable and there are many examples that show that other ways forward are possible. For example: EV manufacturers are creating closed-loop recycling facilities; there are many cities that have successfully reduced car dependence; new electrified public transportation technologies are emerging; two- and three-wheeler vehicles are electrifying rapidly; and in China and Europe, manufacturers are responding to demand for smaller cars.

We already have the technologies to support most of these strategies, but there are political and sometimes social or economic barriers. There are many interventions that can make swift impacts. This could include policy interventions, such as incentivizing smaller batteries; mandatory recycling of batteries; and extending subsidies to e-bikes and second-hand EVs. There are also innovative circular economy business models, such as battery swapping and vehicle refurbishment.

[36] Shanker, R., Chen, C.-C. (J.), & Parsons, R. (2023, January 11). Funding electric public transit can reduce emissions and address economic inequality. *The Conversation.* https://theconversation.com/funding-electric-public-transit-can-reduce-emissions-and-address-economic-inequality-194434

PRINCIPLE 1:

Reduce car dependence

Reducing car dependency has the potential to vastly reduce mineral demand in the transition to zero-emissions road passenger transportation, as it will reduce the number of EVs required to meet future transport needs. Reducing car dependence means that everyday travel is not reliant on private car use, without lowering living standards. This can be achieved by redesigning cities to reduce the need to travel and shifting from private cars to other more efficient transport modes such as public transportation, walking and cycling. It can be implemented through a range of policies and programs including integration of transportation and urban planning, infrastructure investment and financial incentives. It is important to note that many cities have only become car dependent in the last few decades because of direct policies to encourage car use, and that many of the cities known for having good public transport systems were previously highly car dependent and were able to implement changes to reduce car dependency relatively quickly.

Active and public transport modes have lower material requirements than EVs, as well as lower GHG emissions per passenger kilometer. For example, there is 8 kg of lithium in an average EV in the US, which is 1.6 kg per rider at full capacity. In an electric bus there is 44 kg of lithium, which is approximately 0.5 kg per rider.[37] These numbers become more favourable to public transportation once the number of kilometers driven by the vehicles is considered. In addition, most private vehicles are not usually driven at full capacity, for example in the US there is an average of 1.5 passengers per car trip.[38] An e-bike has only 0.02 kg of lithium.

Scenario modeling of the US transport system found that reducing car use and ownership could decrease the demand for lithium by 18 to 66%, as opposed to a decarbonization scenario that keeps US vehicle ownership rates the same.[39] Global modeling of a modest reduction in vehicle ownership by slowing the rate of increase in ownership leads to about 25% less vehicles on the road by 2050, and more than a 25% reduction in mineral demand.[40]

There is an urgent need to decarbonize road passenger transportation, particularly in cities. This will require systemic changes regardless of which technology is prioritised.[41] Although more ambitious strategies to reduce car use will require significant public investment, transitioning to EVs will also have large public and private investment costs including incentives for the vehicles themselves, charging infrastructure, and energy generation and transmission infrastructure.

Although challenging, reducing car dependence is necessary, as relying on EVs alone will not meet climate goals. This has the added benefit of being able to improve transport systems to better meet societal needs, improve liveability, and increase equity and wellbeing, rather than entrench car dependency, ‘lock in’ existing problems with congestion and safety, and exacerbate existing inequalities.

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[37] Riofrancos, T., Kendall, A., Dayemo, K.K., Haugen, M., McDonald, K., Hassan, B., & Slattery, M. (2023). *Achieving Zero Emissions With More Mobility and Less Mining*. Climate and Community Project. https://www.climateandcommunity.org/_files/ugd/d6378b_b03de6e6b0e14eb0a2f6b608abe9f93d.pdf

[38] Davis, S.C., & Boundy, R. G. (2022). Transportation Energy Data Book (Edition 40). United States.

[39] Riofrancos, T., Kendall, A., Dayemo, K.K., Haugen, M., McDonald, K., Hassan, B., & Slattery, M. (2023). *Achieving Zero Emissions With More Mobility and Less Mining*. Climate and Community Project. https://www.climateandcommunity.org/_files/ugd/d6378b_b03de6e6b0e14eb0a2f6b608abe9f93d.pdf

[40] Lopez, F. A., Billy, R. G., & Müller, D. B. (2023). Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles using the global MATILDA model. *Resources, Conservation and Recycling*, *193*, 106951.

[41] Jaramillo, P., S. Kahn Ribeiro, P. Newman, et al. (2022). Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Redesign cities to minimize the need to travel

Urban design influences car use, and factors such as increased density and mixed land use can reduce the number of trips taken by car and shorten the distances travelled.[42] This will then influence per capita car ownership. The 15-minute city is an urban design concept that presumes everyone should be able to access their basic needs within a 15 minute walk or cycle of their home, with benefits for improving quality of life and local economies.[43] A 15-minute city is made up of neighborhoods that are people-friendly, 'complete' and connected with decentralised core services like healthcare and education, essential retail, green spaces and recreation. This will require updated urban planning and zoning regulations to ensure access to these services in every neighbourhood.[44]

There are several cities aiming to implement 15-minute city concepts. For instance, Buenos Aires, Argentina, uses 'ciudad a escala humana' (meaning 'human-scale city'), Portland, in the United States, uses 'complete neighborhoods,' Bogotá, Colombia, refers to 'Barrios Vitales' (meaning 'vital neighborhoods'), Melbourne, Australia, uses '20-minute neighbourhoods,' and Barcelona, Spain, uses 'superblock'.[45] In Buenos Aires, the city has added 110 hectares of new public green space, with the goal that every resident will be within 400 metres of a green space, encouraged fresh food markets in every division of the city and committed to every resident having access to primary healthcare within 15 minutes from home by public transportation.

However, to ensure this strategy leads to a reduction in car use and a switch to more sustainable modes of transport, additional measures are needed. In Portland the city initiated a '20-minute neighbourhood' plan in 2009, with a goal of 90% of residents to be able to easily walk or cycle to meet basic daily needs by 2030. This has been successful in increasing the accessibility of the city from 2010 to 2020, but this did not lead to a reduction in the distance travelled by car within the city.[46] This highlights that a range of measures are needed in addition to increasing accessibility, such as expanding infrastructure for walking, cycling and public transportation, to encourage and enable people to choose not to drive within their neighbourhood.

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[42] Jaramillo, P., S. Kahn Ribeiro, P. Newman, et al. (2022). Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.
[43] United Nations Framework Convention on Climate Change. (2021). *The 15 Minute City.* https://unfccc.int/blog/the-15-minute-city?gclid=CjwKCAjw3POhBhBQEiwAqTCuBsYQnV5iuT4FK_IAHFnC0qNR44uXEMx4Lyfo42FbJsZyBB2k6nGe2BoCArIQAvD_BwE
[44] C40 Cities Climate Leadership Group.. (2021). *How to build back better with a 15-minute city.* https://www.c40knowledgehub.org/s/article/How-to-build-back-better-with-a-15-minute-city?language=en_US
[45] C40 Cities Climate Leadership Group. (2021). *Why every city can benefit from a '15-minute city' vision.* https://www.c40knowledgehub.org/s/article/Why-every-city-can-benefit-from-a-15-minute-city-vision?language=en_US&gclid=CjwKCAjw3POhBhBQEiwAqTCuBm8pg-GISNs6_CNuwFC-KGvGSkorwLJpuh7fnh8AzjGQmH8vd-th0hoCp9IQAvD_BwE.
[46] Chaim, S. (2022). *Portland's 20-Minute Neighborhoods after Ten Years: How a Planning Initiative Impacted Accessibility.* Thesis (Master's)--University of Washington, 2022 http://hdl.handle.net/1773/49275

Shift from private vehicle use to public transportation, walking and cycling

Public and active transportation are crucial to an efficient and equitable transport system that benefits users by reducing vehicle traffic, leading to reduced congestion and emissions.[47] There are various ways to enable the shift from private passenger vehicles towards public and active transportation, among them making public and active transport more convenient, while making car use more expensive.[48]

- **Infrastructure for public transportation, walking and cycling:** To encourage increased use of public transportation, cities must ensure that the service is effectively designed. High-quality public transportation services must be dependable, frequent, speedy, comfortable, easily accessible, affordable, and safe.[49]

  Policy, infrastructure and urban planning are the major determinants of levels of active transport, compared to factors such as weather or geography, evidenced by the many cold, wet and/or hilly climates that have high shares of active transport.[50] Investment in dedicated infrastructure – such as widening sidewalks, crosswalks, bike lanes, and public paths – can significantly boost active transport.[51] Other policies that prioritise active transport and provide incentives for individuals to choose it as their preferred mode of transport – such as replacing car parking spots with bike parking – can also encourage uptake.[52] For example, in Paris investments in cycling infrastructure between 2015 and 2020 led to increases in bike usage of up to 60% over the period, an increase in new cyclists and increased length of cycling trips.[53]

- **Multi-modal transport planning:** Multi-modal transport planning involves considering different transport modes – such as walking, cycling, public transit, and driving – and the connections between them.[54] This approach can help to make public and active transport options more attractive to users. Key principles of multi-modal transport planning include planning mass transit routes, as well as walking and cycling infrastructure, to intersect each other for easy intermodal transfers; integrated payment systems to allow passengers to pay once for trips that include multiple public transit modes and, ideally, a single agency should manage all of a city's public transport systems for seamless integration and smart ticketing.[55]

  There are many examples of cities where multi-modal transport planning has led to significant improvements in public transport. Jakarta, Indonesia has transformed its transport system by shifting focus from cars towards improving mobility. The Jak Lingko scheme integrates fares allowing passengers to travel on public transport for a flat rate within a three-hour window. The physical connectivity between transport options has also been increased, improving connectivity with five national intercity train stations to metro and Transjakarta stations. This will be followed by an upgrade of the first and last-mile connections to transit, and improved connectivity to an additional 44 stations. Walking and cycling infrastructure was improved, including upgrading pedestrian access to stations, better footpaths, a bike-sharing system, bike parking and a plan for a 500 km cycling network. This has resulted in increased service coverage and public transport ridership.[56]

- **Integration of transport and urban planning:** The integration of transport and urban planning can help to encourage uptake of public transport. Approaches include:

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[47] Government of Canada. (n.d.). *Active transportation.* Public Health Agency of Canada. https://www.canada.ca/en/public-health/services/being-active/active-transportation.html
[48] Jaramillo, P., S. Kahn Ribeiro, P. Newman, et al. (2022). Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.
[49] C40 Cities Climate Leadership Group. (2021). *How to make public transport an attractive option in your city*. https://www.c40knowledgehub.org/s/article/How-to-make-public-transport-an-attractive-option-in-your-city?language=en_US
[50] Litman, T. (2023). *Evaluating Active Transport Benefits and Costs: Guide to Valuing Walking and Cycling Improvements and Encouragement Programs*. Victoria Transport Policy Institute. https://www.vtpi.org/nmt-tdm.pdf
[51] Litman, T. (2023). *Evaluating Active Transport Benefits and Costs: Guide to Valuing Walking and Cycling Improvements and Encouragement Programs*. Victoria Transport Policy Institute. https://www.vtpi.org/nmt-tdm.pdf
[52] C40 Cities Climate Leadership Group. (2021). *How to drive a modal shift from private vehicle use to public transport, walking and cycling*. https://www.c40knowledgehub.org/s/article/How-to-drive-a-modal-shift-from-private-vehicle-use-to-public-transport-walking-and-cycling?language=en_US
[53] City of Paris. (2022). *The Paris Cycling Plan (2015-2020).* https://www.paris.fr/pages/paris-a-velo-225
[54] Litman, T. (2022). *Introduction to Multi-Modal Transportation Planning Principles and Practices*. Victoria Transport Policy Institute. https://www.vtpi.org/multimodal_planning.pdf
[55] C40 Cities Climate Leadership Group. (2021). *How to make public transport an attractive option in your city*. https://www.c40knowledgehub.org/s/article/How-to-make-public-transport-an-attractive-option-in-your-city?language=en_US
[56] Sustainable Transport Award. (2021). *Jakarta, Indonesia*. https://www.staward.org/past-winners/njn8kpcckm7tdulhfuregut19pv2tg

- **Transit-oriented development:** Transit-oriented development (TOD) is the concept of concentrating well-designed urban areas around mass-transit nodes, utilizing policies such as increasing building density near transit hubs or corridors, eliminating parking minimums, and implementing measures to discourage driving. It is widely acknowledged as a highly effective approach to sustainable urban planning. For example, in Curitiba in Brazil, TOD policies that promoted denser development along bus rapid transit corridors have contributed to more than 49% of trips being taken in the city by a sustainable mode of transport (public or active transportation).[57]

- **Net-zero precincts:** New concepts are emerging for how existing car-dependent cities can be regenerated and decarbonized through a combination of innovations: renewable energy and storage, electric transport (including vehicles, public transit and micromobility) and smart city integration. Transit activated corridors (TAC) build on the idea of TOD, to regenerate main road corridors through middle suburbs. The idea is to prioritise fast mid-tier public transportation such as electrified rapid bus, light rail or trackless trams with station precincts along main roads.[58] Stations can become localised centres with recharge hubs for battery recharging for shared micromobility such as e-bikes and for electric on-demand transport, which can provide the 'first/last mile linkage' for passengers to complete their trip.

- **Restricting car use:** There are various policy tools for restricting or disincentivizing car use, including:

  - **Congestion charges:** Congestion pricing is a market-based approach to reduce traffic congestion by encouraging off-peak travel or alternate modes of transport. Drawing on a meta-analysis of case studies from Europe, congestion charges were found to lead to a 12-33% reduction in cars in the city-centre.[59] Congestion pricing systems were implemented in Singapore (1975), London (2003), Stockholm (2007), Milan (2008), and New York City (2019) to address traffic congestion and environmental concerns while generating funds for transport improvements.[60]

  - **Restricted traffic areas:** There are several models that restrict or limit traffic to certain areas, usually city centres, at certain times. These include limited traffic zones (LTZs), which prohibit non-residents and unauthorised vehicles from driving at certain times and have been shown to reduce vehicles by 10-20%. For example, Rome, Italy, a city notorious for its traffic, adopted a policy in 1989 of limiting car access to its centre. This scheme was progressively expanded to other areas of the city, and now covers around 10 square kilometers. Access by car is restricted to these areas during certain hours and days of the week to only residents and those who pay an annual fee, and there are fines for those who enter the LTZ when unauthorised. Fines are then used to fund the city's public transportation system. In 2001, electronic access gates were introduced with number plate recognition. Over the same period, there has been significant investment in public transportation and a public fleet of electric scooters. This approach led to a 20% reduction in car traffic during restricted hours, a 10% reduction even during unrestricted hours and greater use of public transportation and two-wheeled transportation.[61]

    Low-emission zones (LEZs) and zero-emission zones (ZEZs) are areas area that allow only low-emission vehicles (LEVs) or zero-emission vehicles (ZEVs), pedestrians, and cyclists to enter freely, while other vehicles may be prohibited or allowed entry for a fee. ZEZs are currently being piloted in a growing number of cities around the world, including Amsterdam, Oslo, Oxford, Paris, and Shenzhen.[62] An evaluation of these schemes found that they are effective at shifting drivers to other modes of transport, but it also found that drivers preferred to switch to EVs than to shift to public

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[57] C40 Cities Climate Leadership Group. (2019). *How to drive a modal shift from private vehicles to public transport, walking and cycling.* https://www.c40knowledgehub.org/s/article/How-to-drive-a-modal-shift-from-private-vehicle-use-to-public-transport-walking-and-cycling?language=en_US
[58] Newman, P., Davies-Slate, S., Conley, D., Hargroves, K., & Mouritz, M. (2021). From TOD to TAC: Why and How Transport and Urban Policy Needs to Shift to Regenerating Main Road Corridors with New Transit Systems. *Urban Science*, *5*(3), 52.
[59] Kuss, P., & Nicholas, K.A. (2022). A dozen effective interventions to reduce car use in European cities: Lessons learned from a meta-analysis and transition management. *Environmental Innovation and Societal Transitions*, 38, 46-64.
[60] Parks, H. (2019, May 29). Investigating the Impact of Congestion Pricing Around the World. *Climate Xchange*. https://climate-xchange.org/2019/05/29/investigating-the-impact-of-congestion-pricing-around-the-world/
[61] CIVITAS. (n.d.). *Implementing Access Restrictions*. https://civitas.eu/mobility-solutions/implementing-access-restrictions
[62] Cui, H., Gode, P., & Wappelhorst, S. (2021). *A global overview of zero-emission zones in cities and their development progress*. https://theicct.org/publication/a-global-overview-of-zero-emission-zones-in-cities-and-their-development-progress/

transportation, so further mechanisms are needed to encourage public transit over private vehicle ownership.[63]

- **Removal of parking spaces:** Policies that eliminate parking spaces and modify traffic routes have been found to be effective in reducing car use. [64] Car use in the city centre of Oslo, Norway reduced by 11% from 2016 to 2018, and by 19% from 2018 to 2019.[65] These reductions were achieved with a gradual approach, involving extenstive consultation, trials and testing, so that citizens could see positive benefits from the changes. The process began in 2014 with a survey of citizens, followed by the 2015 launch of a 'Car-free Livability Programme' to gradually reduce vehicles in the city, including the removal of car parking spaces and the revitalisation of public spaces to be more pedestrian friendly. From 2018, further work was taken including altering traffic routes and new pedestrian and bike infrastructure so that by 2019 nearly 800 parking spaces had been removed. An evaluation of the programme found that car traffic had reduced; drivers made fewer trips; the occupancy rates of cares increased; public transportation and cycling increased; and the majority of Oslo residents are positive about the benefits of fewer vehicles in the city.

- **Financial incentives:** Financial incentives can help citizens overcome the financial barrier of making the switch to more sustainable transport modes.
  - **Expanding subsidies from EVs to other transport modes:** Many governments are providing substantial subsidies for the purchase of EVs, but there are fewer programs that encourage individuals to switch to other low-emission transport alternatives, such as e-bikes or scooters.[66] Several countries and cities provide subsidies for the purchase of a new e-bike, such as a $500 cash-back incentive in Paris, interest-free four-year loans in Scotland and grants of up to 25% of the cost of a bike in Sweden.[67] China has been offering subsidies for e-bikes in rural areas for more than a decade.[68]
  - **Vehicle trade-in programs**: There are several examples of vehicle trade-in programs that can help reduce car dependency by allowing the trade-in of vehicles for subsidies towards other environmentally friendly transport modes beyond EVs. In Lithuania, the Environmental Project Management Agency (APVA) runs a 'cash-for-clunkers' subsidy program, where citizens can receive up to €1000 for trading in their vehicle and purchasing an electric scooter, motorcycle, moped, bicycle, or public transit pass, or 2000 euros towards an EV.[69] The program has had a high uptake, mostly for the purchase of electric scooters and bicycles. Similar programs exist in France for purchasing an e-bike or traditional bike[70] and in British Columbia, Canada, for public transport passes, e-bikes, car share credit, or a rebate towards an EV.[71]

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[63] Isaksen, E. & Johansen, B. (2021). *Congestion pricing, air pollution, and individual-level behavioural responses*. Grantham Research Institute on Climate Change and the Environment. https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2021/06/working-paper-362-Isaksen-Johansen.pdf
[64] Kuss, P., & Nicholas, K.A. (2022). A dozen effective interventions to reduce car use in European cities: Lessons learned from a meta-analysis and transition management. *Environmental Innovation and Societal Transitions*, 38, 46-64.
[65] Figg, H. (2021). *Oslo: Promoting active transport modes*. Eltis. https://www.eltis.org/resources/case-studies/oslo-promoting-active-transport-modes
[66] International Energy Agency. (2022). *Global EV Outlook 2022.* https://www.iea.org/reports/global-ev-outlook-2022
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[68] China.org.cn (2010) China's eastern province introduces e-bike subsidy. http://www.china.org.cn/environment/2010-10/14/content_21121631.htm
[69] Vaitekėnas, P. (2020). Lithuanians splash out on electric scooters in cash-for-clunkers programme. LRT.lt. https://www.lrt.lt/en/news-in-english/19/1260026/lithuanians-splash-out-on-electric-scooters-in-cash-for-clunkers-programme
[70] Köllinger, C. (2022). *French government offering €4,000 to exchange a car for an e-bike*. Eltis. https://www.eltis.org/in-brief/news/french-government-offering-eu4000-exchange-car-e-bike
[71] Scrapit. (n.d.). *SCRAP vehicle rebates and incentives for BC residents*. https://scrapit.ca/

Electric-bus deployment

Worldwide, electric bus deployment is growing rapidly. China currently leads the world in electric bus deployment, and the cities of Shenzhen, Guangzhou and Dalian have already completely transitioned their bus fleets to fully electric.[72] Several countries and regions have committed to having 100% of their new bus procurements be zero-emission technologies. Denmark, New Zealand, and the Netherlands are the most progressive, aiming for 100% new zero-emission bus procurements by 2025.[73] Cities including Los Angeles, Seattle, Copenhagen, Amsterdam, Guangzhou and Nanjing have targets to fully transition their fleets to electric by 2030 or earlier.

The cost of electric buses is a challenge for their deployment. For example, India plans to deploy 50,000 e-buses over the next four to five years; however, each electric bus costs about five times more than a diesel bus, amounting to a total cost estimated at $12 billion, which makes financing a challenge.[74] Despite these higher upfront costs, electric buses have lower operating costs, with lower total costs over the vehicle's lifetime. There are various initiatives underway to overcome the initial challenge of financing:

- **Joint purchasing:** Joint purchasing allows governments to pool their purchasing power and negotiate with bus manufacturers for better prices and warranties for electric buses. In 2015, London and Bogota formed a Global Procurement Initiative (GPI) to accelerate the transition to zero-emission buses in their cities. The cities have committed to purchasing over 18,000 zero-emission buses by 2030, which will reduce greenhouse gas emissions by more than 2.8 million tonnes per year. The initiative also aims to encourage other cities to join the GPI and increase their purchasing power for electric buses, and 24 additional cities have pledged to purchase 40,000 clean buses.[75]
- **Leasing of buses or batteries:** Governments can reduce the initial upfront costs by leasing buses or batteries, and then procuring the services based on performance requirements. As part of the contract the owner and/or manufacturer of the buses or batteries will be responsible for their maintenance, which also reduces risks to governments.[76]
- **Separate bus ownership from operation and maintenance:** Innovative financing models in which electric bus suppliers and public transportation operators partner with new actors (including utility companies and investors) have led to Santiago, Chile having the world's second highest rate of electric bus deployment. Metbus, one of six private bus operators in Santiago, has deployed most of the city's e-buses by partnering with utility company Enel X and bus manufacturer BYD.[77] This partnership began with the pilot of two electric buses in 2017, a year later an additional 100 buses were added, and the current Metbus fleet has more than 400 e-buses. Enel X acts as the financial agent and asset owner, and provides energy for the buses at a discounted rate. Enel X has leased the buses to Metbus, which operates the buses and provides basic maintenance. The bus supplier BYD is responsible for major maintenance. Local authorities are responsible for the distribution of funds from bus fares and provide monthly payments on behalf of Metbus to Enel X for the lease, which are guaranteed regardless of performance.[78]

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[72] C40 Cities Climate Leadership Group. (2020). *How to shift your bus fleet to zero-emission by procuring only electric buses*. https://www.c40knowledgehub.org/s/article/How-to-shift-your-bus-fleet-to-zero-emission-by-procuring-only-electric-buses?language=en_US

[73] Wappelhorst, S., & Rodríguez, F. (2021, December 9). Decarbonizing Bus Fleets: Global Overview of Targets for Phasing Out Combustion Engine Vehicles. *The International Council on Clean Transport.* https://theicct.org/decarbonizing-bus-fleets-global-overview-of-targets-for-phasing-out-combustion-engine-vehicles/

[74] Singh, S.C. (2022, December 17). India's e-bus ambition hits financing speed bump. *Reuters.* https://www.reuters.com/business/autos-transportation/indias-e-bus-ambition-hits-financing-speed-bump-2022-12-17/

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[77] C40 Cities Climate Leadership Group. (2020). *From Pilots to Scale: Lessons from Electric Bus Deployments in Santiago de Chile* https://www.c40knowledgehub.org/s/article/From-Pilots-to-Scale-Lessons-from-Electric-Bus-Deployments-in-Santiago-de-Chile?language=en_US

[78] ZEBRA (2020). Case Study: Metbus Pioneering E-bus Deployments in Santiago. https://c40.my.salesforce.com/sfc/p/#36000001Enhz/a/1Q000000gQSR/ET0.2kS_O5ps_SIFrmwgPiDb95Z6inMj6uljaIcF3mg

Co-benefits

- **Reduced emissions:** Reducing car dependency reduces emissions in multiple ways: by minimizing the use of existing ICEVs and by shifting to active and public transportation. Active and public transportation means lower GHG emissions per passenger, as well as fewer EVs on the road. Less personal EVs mean reduced need for charging, energy generation and transmission infrastructure, all of which have embodied emissions (see box section on page 22 for further details).[79]
- **Equity:** Decarbonization strategies that prioritise active and public transportation, rather than rely on EV uptake, can share the benefits of low-emission transport with more of the population including to low-income households where EV ownership is unaffordable.[80] In most markets outside of China, EVs are only affordable for the most high-income households. For example, in Canada, EVs are too expensive for most residents, and financial incentives to buy EVs have primarily gone to the top 16% income bracket.[81]
- **Improved public health:** A shift toward public and active transportation can lead to public health benefits, such as improved air quality; increased pedestrian safety; and increased physical and mental wellbeing.[82]
- **Liveable communities:** Strategies that reduce reliance on private cars can support the design of more accessible, affordable, liveable and compact communities; can increase community cohesion; and encourage more local economic activity.[83] Investments in public and active transportation can positively impact quality of life for a wider range of the population than electrification of private vehicles.[84]

Enablers

- **Covid-19:** Responses by cities during the pandemic showed that increasing active transport is both achievable and beneficial.[85] Cities worldwide continue to prioritise bicycle lanes as part of their post-lockdown policies. Examples include Milan transitioning 35 km of streets for walking and cycling; Paris converting 50 km of car lanes to bicycle lanes; Seattle permanently closing 30 km of streets to vehicles; and Montreal creating over 320 km of new pedestrian and bicycle paths.[86]
- **Public investment:** Investment in reshaping urban planning and transport systems has high capital costs. However, the transition to EVs also has high public and private costs. Worldwide, in 2021, governments increased their spending on subsidies and incentives for EVs to almost US $30 billion, almost twice the amount spent in the previous year, and China has spent more than US $150 billion since 2009.[87] Modeling of the US transport system estimates that removing ICE vehicles off the roads in 2030 would cost approximately US $550–600 billion.[88]
- **Consumer preferences:** Although it is widely considered that cultural norms emphasizing car ownership can impede the uptake of sustainable transportation, convenience and time are the two biggest factors in transport choices. Cultural norms can shift if public transportation is the most convenient option.[89]

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[79] Winkler, L., Pearce, D., Nelson, J., & Babacan, O. (2023). The effect of sustainable mobility transition policies on cumulative urban transport emissions and energy demand. *Nature Communications*, 14(1), 2357.
[80] Schneider, M. (2022, September 15). Opinion: California is betting on electric cars to clean the air. But will they make it dirtier instead? Los Angeles Times. https://www.latimes.com/opinion/story/2022-09-15/california-electric-vehicles-pollution-traffic-deaths
[81] Shanker, R., Chen, C.-C. (J.), & Parsons, R. (2023). Funding electric public transit can reduce emissions and address economic inequality. The Conversation. https://theconversation.com/funding-electric-public-transit-can-reduce-emissions-and-address-economic-inequality-194434
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[84] Milovanoff, A. (2020, October 22). The myth of electric cars: why we also need to focus on buses and trains. *The Conversation*. https://theconversation.com/the-myth-of-electric-cars-why-we-also-need-to-focus-on-buses-and-trains-147827
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[87] International Energy Agency. (2022). *Global EV Outlook 2022*. https://www.iea.org/reports/global-ev-outlook-2022.
[88] Alarfaj, A. F., Griffin, W. M., & Samaras, C. (2020). Decarbonizing US passenger vehicle transport under electrification and automation uncertainty has a travel budget. Environmental Research Letters, 15(9), 0940c2.
[89] Milovanoff, A. (2020). The myth of electric cars: why we also need to focus on buses and trains. The Conversation. https://theconversation.com/the-myth-of-electric-cars-why-we-also-need-to-focus-on-buses-and-trains-147827

Reducing mineral demand for EVs can help meet climate goals

Across all the principles identified in this report, there is the potential to speed up decarbonization in the road transportation sector. This benefit is particularly clear-cut for principles 1 and 2.

Principle 1: Reduce car dependence

Strategies that reduce mineral demand for EVs also enable a faster transition to a zero-emission road passenger transportation system. Efforts to reduce emissions in the road transportation sector are largely focused on increasing the uptake of EVs, given the high share of emissions from passenger vehicles and the availability of EVs.[90] However, reducing emissions through the adoption of EVs is challenging because of the large scale of the transition, the need to decarbonize electricity systems, differences in the speed of adoption across countries, and the projected increased demand for transport.

Electrification of passenger vehicles will require vast numbers of new EVs, new charging infrastructure and new renewable electricity generation to meet the increased electricity demand from EVs. The speed at which EVs can reduce emissions is limited by how quickly ICEVs can be replaced and how quickly the energy grid is decarbonized.[91] Modeling by Bloomberg found that to achieve net-zero emissions by 2050 in the road transportation sector, 61% of global new passenger vehicle sales need to be zero-emission vehicles by 2030; 93% by 2035; and 100% by 2038. This equates to a global fleet of 612 million passenger EVs in 2035. This is a rapid increase from today: as of mid 2022, there were less than 20 million passenger EVs on the road, which makes up only 1.5% of the proposed global fleet for 2035.[92]

The current uptake of EVs is not enough to meet climate targets. While EV sales are growing rapidly, with a 35% increase in 2023 from 2022, they still account for only 18% of all cars sold. EV sales are concentrated in a few major markets: China with 60% of the market in 2023, Europe with just under 25% and 10% in the US. EV sales still only make up a small share of vehicles sold in many countries such as Brazil, India and Japan.[93]

Only about 25% of the global car market has a policy to ban ICEVs or a target for 100% zero-emission vehicle sales by 2035.[94] Modeling of EV adoption found that most major countries are not on track to reach a full phase out of ICEVs by 2038 based on current policies, although China and some European countries come close.[95] Separate modeling of the US road transport system found that the sector will not meet decarbonization targets if ICEVs are replaced with EVs at the typical rates of replacement based on vehicle lifespans.[96]

In addition, reducing emissions in the sector is even more difficult as demand for transport increases. For example, the International Energy Agency (IEA) scenario to reach net zero by 2050 assumes that passenger cars will increase from 1.2 billion in 2020 to 2 billion in 2050 and passenger travel will double.[97]

[90] Winkler, L., Pearce, D., Nelson, J., & Babacan, O. (2023). The effect of sustainable mobility transition policies on cumulative urban transport emissions and energy demand. Nature Communications, 14(1), 2357.
[91] Riofrancos, T., Kendall, A., Dayemo, K.K., Haugen, M., McDonald, K., Hassan, B., & Slattery, M. (2023). Achieving Zero Emissions With More Mobility and Less Mining. Climate and Community Project. https://www.climateandcommunity.org/_files/ugd/d6378b_b03de6e6b0e14eb0a2f6b608abe9f93d.pdf
[92] BloombergNEF. (2022). *Electric Vehicle Outlook 2022*. https://about.bnef.com/electric-vehicle-outlook/
[93] International Energy Agency. (2024). *Global EV Outlook 2024*. https://www.iea.org/reports/global-ev-outlook-2024
[94] International Energy Agency. (2022). *Global EV Outlook 2022*. https://www.iea.org/reports/global-ev-outlook-2022.
[95] BloombergNEF. (2022). *Electric Vehicle Outlook 2022*. https://about.bnef.com/electric-vehicle-outlook/
[96] Alarfaj, A. F., Griffin, W. M., & Samaras, C. (2020). Decarbonizing US passenger vehicle transport under electrification and automation uncertainty has a travel budget. *Environmental Research Letters*, 15(9), 0940c2.
[97] International Energy Agency. (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*. https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

Reducing car dependency will make it easier to meet climate goals and can provide a more rapid and larger reduction in emissions compared to electrification of vehicles. For example, a study by the City of Sydney, Australia, found that shifting away from car use to active and public transportation would reduce carbon emissions by 23% compared to 7% from electrifying all residential transport.[98] Modeling of the transport system in London, UK found that a rapid and large-scale reduction in car use results in the largest emissions reductions and is necessary to meet carbon targets. To meet the carbon budget for the *"well below 2°C and pursuing 1.5°C"* global temperature target, research suggests that both car travel distance needs to decrease by 72% and ICEVs must be phased out by 2025.[99]

Even a modest reduction in the number of private passenger vehicles will have a significant impact on reducing GHG emissions. Reducing car dependency has benefits for reducing GHG emissions in multiple ways. First, it will minimize the use of existing ICEVs. Second, shifts to active and public transportation will lower emissions as they have lower GHG emissions per passenger; for example, a study in India found that electric buses have 71% lower emissions than private EVs.[100] And lastly, fewer EVs will be required to electrify all passenger vehicles, as well as less charging, energy generation and transmission infrastructure, which all have embodied emissions.

Reducing demand for travel by private vehicles creates the most immediate reductions in emissions, without the need to wait for the deployment of new technologies. In addition, the earlier emissions reductions are achieved, the greater their impact on cumulative emissions and climate impacts.[101]

Principle 2: Shift to smaller and more efficient vehicles and batteries

Smaller-sized vehicles and batteries can also speed up the decarbonization of the road passenger transport system, as they are more affordable and have lower emissions from manufacturing. The total GHG emissions over the lifespan of an EV are approximately half of those of ICEVs, and this reduces to approximately 25% with low-carbon electricity. However, EVs have approximately 30 to 50% higher GHG emissions than ICEVs from the embedded emissions in their production.[102] The production of LIBs (including the extraction and processing of minerals and battery manufacturing) accounts for 40 to 60% of these embedded emissions.[103] The emissions from EV production can firstly be reduced by reducing vehicle (and therefore battery) size, as a large EV can have a battery two to three times larger than a small EV.[104] Electric micromobility (e-bikes, standing scooters), two-wheelers (scooters, motorbikes) and three-wheelers (rickshaws) all require much smaller batteries again. Emissions can also be reduced using recycled battery materials, which typically have a carbon footprint that is 25% of that from raw materials from primary sources.[105] If vehicle and battery sizes continue to increase, this could erode some of the GHG emission benefits of transitioning to EVs.[106]

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[98] City of Sydney. (2023). *Have your say: Electrification of transport in the city*. https://www.cityofsydney.nsw.gov.au/vision-setting/have-your-say-electrification-of-transport-in-the-city

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[100] International Transport Forum (2023) *Life-Cycle Assessment of Passenger Transport: An Indian Case Study*. https://www.itf-oecd.org/sites/default/files/docs/life-cycle-assessment-passenger-transport-india.pdf

[101] Winkler, L., Pearce, D., Nelson, J., & Babacan, O. (2023). The effect of sustainable mobility transition policies on cumulative urban transport emissions and energy demand. *Nature Communications*, 14(1), 2357.

[102] Note this is based on a 40kWh battery. International Energy Agency. (2022). *The Role of Critical Minerals in Clean Energy Transitions.* https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

[103] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries

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[105] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries

[106] International Energy Agency. (2022). *Global EV Outlook 2022.* https://www.iea.org/reports/global-ev-outlook-2022.

CASE STUDY 1:

TransMilenio Bus Rapid Transit System in Bogotá, Columbia

In the 1990s, Bogotá, Colombia had poor air quality and heavy traffic congestion. This was caused by rapid population growth, an increase in private vehicles and inadequate public transportation systems. Mayor Enrique Peñalosa proposed TransMilenio, a new Bus Rapid Transit (BRT) System, with the aim of improving the city's public transportation system, economy, environment, and residents' wellbeing.[107]

The design of TransMilenio centred on dedicated bus lanes for TransMilenio buses mainly along service 'trunks' ('troncales' in Spanish). These bus lanes typically run down the centre of a main street and passengers reach the bus stops via a bridge. There are also 'feeder' buses that provide transport from major stops to residential areas, without dedicated bus lanes.[108] The system has an integrated smart card payment system and fares cover the use of feeder buses.

The major benefit of BRT systems is that they can be deployed quicker and are more cost-effective than a metro or rail system. The TransMilenio system was able to begin operating in a short timeframe by using a phased approach. In 1999, a new transit authority, TransMilenio S.A., was established. The system was launched in 2000 with 41km of bus routes, which has expanded to 12 routes with more than 110 km of bus lanes.[109]

The project has resulted in reduced passenger travel time of 30%, a 92% reduction in road-related deaths, decreased car use (9% of passengers previously commuted by private car), and a 40% reduction in air pollutants.[110] However, while the system is a significant improvement on the previous bus systems, there are some ongoing improvements to address overcrowding, delays and safety concerns.

The successful implementation of Bogota's TransMilenio system led to the development of a National Urban Transport Plan in Colombia.[111] The Colombian government replicated the project in Pereira and Cali, proving the system's scalability and adaptability to metropolitan areas of less than 1 million inhabitants without affecting its performance and economic viability.[112]

Key success factors include:

- **Stakeholder engagement:** Design and planning of the project was carried out by several public agencies, overseen by TransMilenio S.A., and with input from the private sector including bus operators from the previous bus system, local and international consultants and the World Bank.[113]
- **Public-private partnership:** TransMilenio S.A. has the responsibility of planning the system and overseeing operations. The Instituto de Desarrollo Urbano [the Institute of Urban Development] (IDU) was responsible for the construction and maintenance of infrastructure. Operation and maintenance of the buses is undertaken by the private sector. [114]

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[109] Center for Public Impact. (2016). *TransMilenio: renewing Bogotá's transport system*. https://www.centreforpublicimpact.org/case-study/transmilenio..
[110] Ibid
[111] Urban Sustainability Exchange. (2017). *TransMilenio Bus Rapid Transit System*. https://use.metropolis.org/case-studies/transmilenio-bus-rapid-transit-system
[112] Ibid.
[113] Center for Public Impact. (2016). *TransMilenio: renewing Bogotá's transport system*. https://www.centreforpublicimpact.org/case-study/transmilenio.
[114] Urban Sustainability Exchange. (2017). *TransMilenio Bus Rapid Transit System*. https://use.metropolis.org/case-studies/transmilenio-bus-rapid-transit-system

- **Financial feasibility and sustainability:** The initial cost of Phase 1 was US $240 million. Public financing for the system was 46% from a fuel tax, 28% local revenues, 6% credit from the World Bank and 20% national government grants.[115] Phase 2 was US $545 million and 66% financed by the national government.[116]
- **Technical feasibility:** TransMilenio was modelled off similar bus transport systems in Curitiba, Brazil; and Quito, Ecuador. The design was based on lessons learned from these and other systems. The system was designed to ensure connection with existing transport systems.
- **Political commitment, public buy-in, adequate resources and incentives for performance of private sector:** The success of the project also relied on the high priority given by the city government and significant public investment, communication strategies to gain public buy-in, the allocation of sufficient technical and financial resources and incentives for private sector operation of buses through tendering and contracts.[117]

The city was awarded the inaugural Sustainable Transport Award in 2005 for TransMilenio, the integration of bicycle infrastructure with mass transportation, as well as redefining and reclaiming public areas for its residents.[118] It won the Sustainable Transport Award once again in 2022 for interventions including new bike lanes, repurposing land for pedestrian use and improving safety and reducing air pollution, particularly for children and low-income residents. During the Covid-19 pandemic, Bogotá created 84 km of emergency bike lanes resulting in a 400% increase of bike use on some roads. 28 km of these bike lanes have become permanent, and 46 km are still in use. The city also reconfigured street space to allow for better social distancing and pedestrianised streets once only served by cars. The city is also deploying e-buses with one of the largest fleets outside of China.[119]

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[115] Center for Public Impact. (2016). *TransMilenio: renewing Bogotá's transport system*. https://www.centreforpublicimpact.org/case-study/transmilenio.
[116] Urban Sustainability Exchange. (2017). *TransMilenio Bus Rapid Transit System*. https://use.metropolis.org/case-studies/transmilenio-bus-rapid-transit-system
[117] Ibid.
[118] Sustainable Transport Award. (2005). *Sustainable Transport Award. Bogotá, Colombia*. https://www.staward.org/past-winners/2005-bogota-colombia.
[119] Sustainable Transport Award. (2022). *2022 Winner: Bogotá, Colombia*. https://www.staward.org/past-winners/2022-bogot-colombia.

CASE STUDY 2:

Connecting the suburbs to public transport in Auckland, New Zealand

Electric on-demand public transit refers to a transportation service that operates similarly to ride-hailing services through a smartphone app, with small vehicles providing trips within a specific zone, without fixed routes or schedules. Vehicles such as minibuses can take passengers wherever they need to go within a set area and are guided by an algorithm that optimises routing for pick-ups and drop-offs.[120] The cost of on-demand public transit is comparable to that of traditional buses, and payments and transfers between transit services are often integrated, making it more affordable than typical car-sharing services.[121]

A key benefit of electric on-demand services is connecting passengers to major transport hubs. This increases the likelihood that passengers will use public transportation over a private car for longer trips and reduces the use of private cars for short trips to transport hubs. On-demand electric-public transportation can help to increase public transportation use in underserved suburban and rural areas that are not dense enough for traditional public transportation investment, supporting more equitable access to public transportation.[122] On-demand small-sized vehicles can speed up decarbonization, as they are easier to procure than large electric buses, and require less charging infrastructure.

New Zealand's Auckland Transit (AT) launched its On-Demand & Shared Mobility Roadmap in 2020. The roadmap identifies that on-demand and shared services can be utilized for two objectives: to provide a connection for the first or last leg of a trip to the transport network, as less than half of Auckland's population is within walking distance of it; and to replace existing public transportation routes with on-demand or shared services, which could offer better value for money while improving customer access.

The Roadmap is driven by 12 principles, including that walking, cycling and active travel should be the most attractive choice for short trips and that on-demand and shared services should support a transition to clean, green and space-efficient travel choices, and support the existing transportation system.[123]

Auckland Transit piloted on-demand transport shuttle services AT Local in November 2018 in the suburb of Devonport. The service operated fully electric vehicles and offered customers a corner-to-corner shuttle service within the trial area. The trial aimed to address concerns about congestion and parking at existing ferry terminals, as well as to provide a more sustainable and convenient transportation option for the community.

The service had delivered over 30,000 rides in the first year of the pilot, with ridership increasing week-on-week. It was reported that 43% of riders had moved away from private motor vehicles. The service was initially supported by a subsidy of NZ $35 per ride, which was reduced to below NZ $11.75 per ride by August 2019.[124] User feedback was generally positive, however, following public consultation with the community, it was decided the on-demand service would be discontinued in February 2021 and the existing bus services would be kept and improved.[125]

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[120] Kaufman, B., & Hughes, A. (2022). Electric on-demand public transport is making a difference in Auckland – now it needs to roll out further. *The Conversation*. https://theconversation.com/electric-on-demand-public-transport-is-making-a-difference-in-auckland-now-it-needs-to-roll-out-further-189438

[121] Ibid

[122] Ibid

[123] Auckland Transport (2020). *On-demand Shared Mobility Roadmap*. https://at.govt.nz/media/1981832/j004697-on-demand-shared-mobility-roadmap_v7_compressed.pdf

[124] Auckland Transport (2021). *On-demand Shared Mobility Roadmap*. https://at.govt.nz/media/1981832/j004697-on-demand-shared-mobility-roadmap_v7_compressed.pdf

[125] Auckland Transport (n.d.). *Devonport AT Local and bus service changes.* https://at.govt.nz/projects-roadworks/devonport-at-local-and-bus-service-changes/

A new AT Local service was trialled for 12 months beginning in October 2021 in the suburbs of Conifer Grove, Takaanini and Papakura, replacing a low-performing diesel bus route. The service uses technology from Liftango and is designed to better integrate with public transportation following feedback from the initial trial. Passengers can pay fares using the same card as for other public transportation, and the fares are the same as a local bus fare. There are nearly 400 pick-up and drop-off points in the service zone, including railway stations, and passengers have a maximum of around 120 metres (3-minute walk) at either end of their journey.[126] It is estimated the service will cut annual emissions by 100,000 kg and provide access to public transportation to 6,400 residents, 38% more people than the previous bus service.[127]

The example from Auckland shows that this new type of transport can reduce private car use for short trips and increase accessibility of public transportation by providing first/last mile linkages in areas underserved by public transportation.

[126] Liftango. (2021, October 22). *New On-Demand Transport Service in South Auckland.* https://www.liftango.com/resources/new-on-demand-transport-service-in-south-auckland
[127] Kaufman, B & Hughes, A. (2022, August 31). Electric on-demand public transport is making a difference in Auckland – now it needs to roll out further. *The Conversation.* https://theconversation.com/electric-on-demand-public-transport-is-making-a-difference-in-auckland-now-it-needs-to-roll-out-further-189438

PRINCIPLE 2:

Shift to smaller and more efficient vehicles and batteries

EVs are an essential technology for decarbonizing road transport, particularly in remote and regional areas where it is more difficult to reduce car dependence. This principle is focused on how the mineral demand of an EV can be reduced – first, by using smaller vehicles and second, by improving the efficiency of battery design and manufacturing.

Reducing the size of EVs and batteries is a clear-cut, impactful way to reduce mineral demand with a large potential impact. Smaller-sized EVs require much smaller batteries than a larger vehicle would need to travel the same distance. There are various studies which have quantified the reduction in mineral demand for scenarios which limit the size of batteries, for example:

- Global modeling of a shift towards smaller vehicles found that this could reduce cumulative material demand for batteries until 2050 by up to 25%;[128]
- Modeling of the US transport system found that the annual demand for lithium in 2050 could be reduced by 42% by limiting the battery size of EVs;[129]
- The IEA estimates that if battery sizes remained equal to today instead of increasing as projected, 16% of incremental battery metal demand could be avoided by 2030.[130]

This strategy would require reversing the global trend towards SUVs and larger vehicles, which can have batteries two or three times the size of smaller vehicles. Preference for large vehicles and batteries is partly driven by a desire for longer-ranging batteries, but these vehicles often have a range that is unnecessarily large for how they are used. This leads to the underutilization of the significant material and energy resources that go into battery production. Small EVs can speed up the decarbonization of the road passenger transportation system as they are more affordable and have lower emissions from manufacturing. Smaller EVs are also more efficient, so they require less electricity to travel the same distance. They are also safer for pedestrians and cyclists in the event of road accident.

Increasing the efficiency of battery design has the potential to reduce mineral demand, as smaller amounts of minerals are required to manufacture a battery that can store the same amount of energy, and the auto industry is making significant progress towards this. There are currently low levels of recycled content used in battery manufacturing, and improving this could reduce demand for primary minerals, as well as significantly reduce the embedded GHG emissions of an EV. Shifts in battery chemistries or to new battery technologies can reduce demand for specific metals, such as cobalt, but may not lead to a net reduction in overall mineral requirements. The benefits of improving the efficiency of the battery design and manufacturing will be offset if batteries are used in large EVs.

[128] Lopez, F. A., Billy, R. G., & Müller, D. B. (2023). Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles using the global MATILDA model. *Resources, Conservation and Recycling*, *193*, 106951.
[129] Riofrancos, T., Kendall, A., Dayemo, K.K., Haugen, M., McDonald, K., Hassan, B., & Slattery, M. (2023). *Achieving Zero Emissions With More Mobility and Less Mining*. Climate and Community Project. https://www.climateandcommunity.org/_files/ugd/d6378b_b03de6e6b0e14eb0a2f6b608abe9f93d.pdf
[130] International Energy Agency. (2022). *Global EV Outlook 2022*. https://www.iea.org/reports/global-ev-outlook-2022.

Smaller-sized vehicles

Reducing the size of vehicles and batteries has a large potential to reduce mineral demand. There is a direct relationship between the size of vehicles and the weight, and therefore mineral demand, of the battery.[131] Battery weights can vary widely: a review of LIBs estimates that small EVs have average battery weights of around 160 kg, medium-sized around 300 kg and large-sized 480 kg.[132] Sales data from France, Germany and the UK in 2022 shows that the battery in an SUV can be twice as large as that in a small EV, with 75% more critical minerals and 70% more GHG emissions from manufacturing.[133]

The design of EVs and batteries determines their efficiency, that is, the distance that can be travelled for the same amount of electricity stored in the battery (measured in kWh). The size of the vehicle is the most important influence on this, and smaller EVs are more efficient than large EVs. Larger EVs are heavier and require bigger batteries to be able to travel the same distance as smaller EVs. Larger vehicles not only require more minerals for the battery, but also increase mineral requirements for energy generation and transmission infrastructure, as they require more electricity to power them than a smaller EV.[134]

However, across global EV markets (as well as ICEVs) there is a trend towards SUVs and large car models. In 2022, nearly 60% of all available EV models across global markets were SUVs or large models.[135] This has shifted rapidly since 2019 where small and medium EVs were the majority of the market. The growing size of vehicles has led to an increase in the average battery size of EVs by 60% between 2015 and 2021.[136]

The growth in battery size is primarily driven by the desire of EV automakers to increase battery range, to enable drivers to travel longer distances.[137] However, the trend towards larger and longer-range batteries is leading to a mismatch between battery sizes and driving requirements. In the US, the average range of small EVs sold in 2022 was 350 km,[138] but 95% of trips are less than 48 km (30 miles).[139] Longer-range batteries will also become less necessary as charge infrastructure is more widely available. Batteries that are larger than needed are leading to the underutilization of the significant material and energy resources that go into battery production.

The trend towards larger vehicles is most evident in the US where over 80% of the EV market is SUVs and ICEVs, and there are only a small number of small-sized EVs on the market. Small-sized vehicles in the US also have larger batteries than small-sized vehicles in other countries – the battery range of a small car in the US is 60 kWh compared to 35 kWh in France, Germany and the UK.[140]

In China, where EV adoption is highest, the best-selling vehicles are small models, despite there also being a trend towards larger EVs. The two best-selling vehicles, the Wuling Hongguang Mini EV and the BYD Dolphin, make up 15% of market share.[141] Two- or three-wheeler vehicles, which require much smaller batteries, are the most electrified market segment. China also has a largest market for electric two-wheelers (scooters and motorbikes), followed by Vietnam. In India, three-wheelers (rickshaws) are electrifying rapidly, with more than half of those sold in 2022 being electric.[142]

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[131] Baars, J., Cerdas, F., & Heidrich, O. (2023). An integrated model to conduct multi-criteria technology assessments: the case of electric vehicle batteries. *Environmental Science & Technology*, *57*(12), 5056-5067.1``
[132] Lopez, F. A., Billy, R. G., & Müller, D. B. (2023). Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles using the global MATILDA model. *Resources, Conservation and Recycling*, *193*, 106951.
[133] International Energy Agency. (2023). *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023
[134] Brinn, J. (2023). *Building Batteries Better: Doing the Best With Less*. Natural Resources Defense Council. https://www.nrdc.org/resources/building-batteries-better-doing-best-less
[135] International Energy Agency. (2023). *Global EV Outlook 2023.* https://www.iea.org/reports/global-ev-outlook-2023
[136] International Energy Agency. (2022). *Global EV Outlook 2022.* https://www.iea.org/reports/global-ev-outlook-2022.
[137] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries
[138] International Energy Agency. (2023). *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023
[139] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries
[140] International Energy Agency. (2023). *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023
[141] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries
[142] International Energy Agency. (2023). *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023

Efficient battery design and manufacturing

There have been large improvements in the material efficiency of batteries, that is the amount of material required to produce the same capacity battery (also known as material intensity). This has been largely driven by the high cost and high carbon footprint of EV batteries. Strategies to increase the efficiency of material use in batteries include:

- **Improving energy density:** Energy density, the amount of energy that can be stored in the same weight battery, has dramatically improved for LIBs. Energy density almost tripled at the cell level between 2010 and 2020. There is potential to further increase energy density through chemistry changes such as silicon-doped graphite and lithium metal anodes.[143]
- **Manufacturing with recycled content:** The use of recycled content can minimize demand for primary sources (although will not reduce total mineral demand). Recycled battery materials are not widely used, although technologically possible. Currently, only a small portion of materials from battery manufacturing comes from recycled sources for cobalt and nickel and there is likely little to no recycled lithium.[144]

Reducing cobalt content and new battery designs

There is a trend towards reducing the cobalt content of LIBs. Nickel-based battery chemistries that contain cobalt, namely nickel manganese cobalt (NMC), are most commonly used for EVs in European and American car markets. NMC chemistries are trending towards higher nickel and lower cobalt concentrations. There is also a resurgence in the market for lithium iron phosphate (LFP) batteries, which made up 40% of the market in 2023, up from almost 30% in 2022 and 25% in 2021, in part because they contain no cobalt and nickel, as well as being safer and cheaper. LFP batteries were previously not used widely outside of China as they have lower energy densities than nickel-based chemistries, but are now being considered by automakers more widely.[145] It is important to note that reducing cobalt may lead to an increase in demand for other minerals, including nickel and phosphorus, which also face environmental and human rights challenges.[146] For example, modeling of a shift towards more LFP batteries found it could increase demand for graphite by 11%, aluminium by 24%, copper by 24% and phosphorus by 154%.[147] Phosphorus is an essential nutrient for food production with no replacement, and there is a risk battery production could further add pressure to security of supply, price volatility and human rights issues in the supply chain, and therefore food security.[148]

The industry is also experimenting with new battery designs with lower critical material intensity, such as solid-state batteries and manganese-rich cathode chemistry lithium nickel manganese oxide (LNMO). There is also research into lithium-free battery chemistries, the most promising of which is sodium-ion (Na-ion). Na-ion has been commercially introduced in China by CATL; however, the low energy density is a challenge for the broader uptake for EVs. As of 2023, there are nearly 30 Na-ion battery manufacturing plants operating, planned or under construction, mostly in China, and several automakers have announced Na-ion EVs.[149]

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[143] Ibid
[144] Dominish, E., Florin, N., Wakefield-Rann, R. (2021). *Reducing new mining for electric vehicle battery metals: responsible sourcing through demand reduction strategies and recycling*. Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. https://earthworks.org/resources/recycle-dont-mine/
[145] International Energy Agency. (2024). *Global EV Outlook 2024*. https://www.iea.org/reports/global-ev-outlook-2024
[146] Spears, B. M., Brownlie, W. J., Cordell, D., Hermann, L., & Mogollón, J. M. (2022). Concerns about global phosphorus demand for lithium-iron-phosphate batteries in the light electric vehicle sector. Communications Materials, 3(1), 14.
[147] Lopez, F. A., Billy, R. G., & Müller, D. B. (2023). Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles using the global MATILDA model. *Resources, Conservation and Recycling*, *193*, 106951.
[148] Spears, B. M., Brownlie, W. J., Cordell, D., Hermann, L., & Mogollón, J. M. (2022). Concerns about global phosphorus demand for lithium-iron-phosphate batteries in the light electric vehicle sector. *Communications Materials*, *3*(1), 14.
[149] International Energy Agency. (2023). *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023

Co-benefits

- **Affordability:** Smaller vehicles and batteries are typically more affordable, which can increase EV uptake and speed up the removal of ICEV vehicles from the road. For example, in China where small EVs have a higher market share than in other countries, EVs are only approximately 10% higher in cost than conventional vehicles. In other countries they are typically 45-50% more expensive.[150]
- **Reduced emissions:** Reducing vehicle (and therefore battery) size, can help to reduce the high embedded emissions of EVs, which are mostly from LIB production. Emissions can also be reduced through the use of recycled battery materials which typically have a carbon footprint that is one quarter than that of raw materials from primary sources.[151]
- **Safety:** Smaller-sized vehicles are safer for pedestrians, as SUVs and large cars have higher rates of fatalities in the event of a road accident.[152] There were more than 7,500 pedestrians killed by drivers in the US in 2023, and this number has been growing since 2010, partly due to the increased prevalence of SUVs.[153]

Enablers

- **Policy incentives:** Various policies could be implemented to encourage small-sized vehicles, for example linking the size of subsidies to battery sizes or differentiated tax rates for vehicles based on size.[154] This can help to counteract the motivation of automakers towards producing SUV and large car models, which are generally more profitable.[155]
- **Increased availability of chargers:** If chargers are widely available (particularly fast chargers) this decreases 'range anxiety' so drivers don't feel that large cars with long range batteries are as necessary. On-road charging systems are in development that provide 'dynamic charging' to charge vehicle batteries while driving. These systems are currently in the R&D stage, and there are several pilots. For example, Sweden opened the world's first electrified road with 2 km of electric rail embedded in a public road connecting Arlanda airport to a logistics site outside Stockholm.[156]

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[150] International Energy Agency. (2022). *Global EV Outlook 2022*. https://www.iea.org/reports/global-ev-outlook-2022.
[151] McKinsey & Company. (2021). *The race to decarbonize electric-vehicle batteries*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries
[152] Arbelaez, R. (2023, March 9). As heavy EVs proliferate, their weight may be a drag on safety. *Insurance Institute for Highway Safety (IIHS)*. https://www.iihs.org/news/detail/as-heavy-evs-proliferate-their-weight-may-be-a-drag-on-safety
[153] Kim, J. (2023, June 26). U.S. pedestrian deaths reach a 40-year high. *NPR.* https://www.npr.org/2023/06/26/1184034017/us-pedestrian-deaths-high-traffic-car
[154] International Energy Agency. (2022). *Global EV Outlook 2022*. https://www.iea.org/reports/global-ev-outlook-2022.
[155] International Energy Agency. (2023). *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023
[156] Carrington, D. (2018). World's first electrified road for charging vehicles opens in Sweden. *The Guardian*. https://www.theguardian.com/environment/2018/apr/12/worlds-first-electrified-road-for-charging-vehicles-opens-in-sweden

CASE STUDY 3:

BYD Battery Redesign

BYD Battery has developed a novel Blade Battery design that improves the energy density and safety of LFP batteries. BYD Battery, a subsidiary of the Chinese multinational BYD Company, specialises in the manufacturing of rechargeable batteries for EVs and energy storage systems. Founded in 1995, it has become a major player in the global battery market, with its products used in various applications, including electric cars, buses, and trucks, as well as energy storage systems for residential and commercial use.[157]

BYD's Blade battery features a thin and long design, resembling a blade, with positive and negative terminals on each end that provide structural integrity to the battery pack. LFP technologies are safer than traditional nickel-based lithium-ion chemistries, such as NMC, but have not been popular with EV manufacturers outside of China because of their lower energy density. The Blade design allows more cells to fit in the same space battery pack, resulting in higher energy density, more power and a lighter weight compared to typical LFP batteries.[158] There is speculation that Blade Batteries could reach comparable levels of energy density to standard NMC batteries.[159] In addition, the BYD Blade Battery design eliminates the need for separate battery modules, allowing for more flexibility in design and capacity optimisation.[160]

The use of these batteries is expanding. Tesla has begun to use the safer BYD Blade batteries in its Tesla Y cars manufactured at the Berlin Gigafactory, with plans to expand the usage of these batteries to other factories. It is has also been reported that a new type of Blade Battery will be used in Tesla's Model 2, an affordable EV with a proposed price tag of under US $25,000.[161]

An additional benefit of the BYD battery is safety, which is a major concern in the development of EVs. Crashes can cause LIBs to combust and explode, as they are prone to thermal runaway and combustion if punctured or damaged. Many EV manufacturers have experienced battery fires due to overheating and other unknown reasons. The BYD Blade Battery has undergone several safety tests, which demonstrated that the Blade Battery has a higher level of safety than traditional LIBs. The battery has passed tests without any incidents of fire or explosion, including being punctured by a nail, crushed and bent, being heated to 300°C and being overcharged by 260%.[162]

The new larger cell design may enable direct recycling, which recovers the high value cathode materials for reuse in battery manufacturing.[163] The blade design, which stores cells directly inside, without typical modules and the need for wires and adhesives, means the cells can be easily disassembled by hand.[164] BYD has stated that direct recycling could make the recycling of LFP batteries economical.[165]

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[157] BYD Company. (n.d.). Company introduction. https://www.bydglobal.com/en/CompanyIntro.html
[158]Pundir, A. S. (2023, February 26). Here's How BYD's Blade Battery Superior To Tesla Lithium-Ion Packs. *HotCars*. https://www.hotcars.com/byds-blade-battery-superior-to-tesla-lithium-ion-packs/
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[160] Meng, X., & Zheng, E. Y. (2021). The Next-Generation Battery Pack Design: from the BYD Blade Cell to Module-Free Battery Pack. *Battery Bits*. https://medium.com/batterybits/the-next-generation-battery-pack-design-from-the-byd-blade-cell-to-module-free-battery-pack-2b507d4746d1
[161] Pundir, A. S. (2023, February 26). Here's How BYD's Blade Battery Superior To Tesla Lithium-Ion Packs. *HotCars*. https://www.hotcars.com/byds-blade-battery-superior-to-tesla-lithium-ion-packs/
[162] BYD. (2020). BYD's New Blade Battery Set to Redefine EV Safety Standards. https://en.byd.com/news/byds-new-blade-battery-set-to-redefine-ev-safety-standards/
[163] Gaines, L., Dai, Q., Vaughey, J. T., & Gillard, S. (2021). Direct recycling R&D at the ReCell center. *Recycling*, *6*(2), 31.
[164] Morse, I. (2021). A Dead Battery Dilemma. *Science*. https://www.science.org/content/article/millions-electric-cars-are-coming-what-happens-all-dead-batteries
[165] Gaines, L. (2018). Lithium-ion battery recycling processes: Research towards a sustainable course. *Sustainable materials and technologies*, *17*, e00068.

PRINCIPLE 3:

Use vehicles and batteries more intensively over their lifespan

Using EVs and batteries more intensively during their lifespan, and extending the length of their lifespan, can reduce the number of new EVs and batteries needed to meet the same requirements and therefore reduce mineral demand. There are a range of strategies to achieve this, for example:

- Remanufacturing and repurposing of EV batteries at end-of-life, extends the lifespan of batteries so they can be used again in EVs or in other applications, such as stationary energy storage
- Reuse of second-hand EVs, extends the lifespan of the vehicle and battery
- EV-sharing, such as car-sharing, ridesharing or carpooling, ride-sourcing or ride-hailing and taxi services and car rental, uses vehicles more intensively during their lifespan
- Battery-sharing, such as battery-leasing and swapping schemes, uses batteries more intensively during their lifespan.

Of these strategies, repurposing EV batteries for stationary storage has the highest potential to reduce mineral demand. Vehicles are often retired before the end of their useful life and at this point the majority of batteries are suitable for repurposing.[166] Modeling of reuse of EV batteries for replacement or for stationary energy storage found that mineral demand could be reduced by 18% by 2050.[167] However, the stationary storage market is much smaller than the EV market and eventually, batteries that are suitable for repurposing will need to be recycled once demand for stationary storage has been met. It is estimated that second-life batteries could effectively cover the demand for energy storage for solar photovoltaic (PV) systems in Germany and France by 2030.[168]

Reuse of second-hand EVs after their first life can extend the vehicle and battery lifespan, and it is estimated that extending battery lifespans from 12 to 16 years could reduce mineral demand by 7% by 2050.[169] Reuse of second-hand EVs is growing as the market matures, but is limited by accessibility in certain markets, uncertainty surrounding the condition and performance of batteries and a lack of repairability.

Remanufacturing of EV batteries for use again in EVs is an emerging idea, however, it will likely only be applicable to a small number of batteries that reach end-of-life within five years, with research estimating it could only meet a small percentage of battery demand each year.[170] All these strategies will require batteries to be designed so they are durable, repairable, and can be easily, safely and economically handled.

Sharing of EVs has the potential to decrease the overall number of new EVs required. However, the extent to which this strategy can reduce mineral demand is unknown, as it is dependent on if vehicle ownership is reduced; if there is an increase or decrease in the number of trips taken by cars; and the impacts on vehicle and battery lifespans.[171]

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[166] Canals Casals, L., Etxandi-Santolaya, M., Bibiloni-Mulet, P. A., Corchero, C., & Trilla, L. (2022). Electric Vehicle Battery Health Expected at End of Life in the Upcoming Years Based on UK Data. *Batteries*, 8(10), 164.
[167] Lopez, F. A., Billy, R. G., & Müller, D. B. (2023). Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles using the global MATILDA model. *Resources, Conservation and Recycling*, *193*, 106951.
[168] Kastanaki, E., & Giannis, A. (2023). Dynamic estimation of end-of-life electric vehicle batteries in the EU-27 considering reuse, remanufacturing and recycling options. *Journal of Cleaner Production*, *393*, 136349.
[169] Lopez, F. A., Billy, R. G., & Müller, D. B. (2023). Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles using the global MATILDA model. *Resources, Conservation and Recycling*, *193*, 106951.
[170] Kastanaki, E., & Giannis, A. (2023). Dynamic estimation of end-of-life electric vehicle batteries in the EU-27 considering reuse, remanufacturing and recycling options. *Journal of Cleaner Production*, *393*, 136349.
[171] He, L., Mak, H. Y., Rong, Y., & Shen, Z. J. M. (2017). Service region design for urban electric vehicle sharing systems. *Manufacturing & Service Operations Management*, 19(1), 97-114.

Car sharing is still small in scale compared to private car trips, but the technology is established, and consumer preferences and policy incentives are encouraging uptake and the shift towards EV fleets. There is some evidence that car sharing reduces vehicle ownership and the need for new cars, and could therefore reduce mineral demand. Alternatively, ride-sourcing and ride-hailing apps are likely to encourage additional trips and shift away from public transportation, which could therefore lead to a net increase in new vehicles.

Sharing of batteries through battery-leasing and swapping programs could reduce mineral demand in several ways, but this is currently unquantified. It can encourage the use of smaller batteries, as batteries can be swapped quickly, compared to charging batteries, which is typically slow and leads to passengers preferring larger batteries which don't need to be charged as frequently. Sharing may also have the additional benefits of increasing battery lifespan through maintenance and repair and increasing the likelihood of reuse and recycling at end-of-life.

Remanufacturing and repurposing of EV batteries at end-of-life

Remanufacturing of EV batteries refers to refurbishing batteries at end-of-life so they can be used in their original application, to a standard which is equivalent to a new battery.[172] LIBs degrade with use and their storage capacity decreases over time. Once batteries reach end-of-life, their state of health (SoH) – the remaining percentage of original manufactured energy storage capacity – can be measured. If batteries still have a SoH of more than 85%, they can be suitable for remanufacturing for use in EVs.[173] It is estimated that batteries that reach end-of-life within five years typically have a SoH above 90%, and could therefore be suitable for remanufacturing.[174]

Remanufacturing of LIBs would be done by dismantling the battery into cells, testing the SoH, replacement of degraded cells and reassembly. Research suggests that the SoH can be restored to almost 100% by replacing a small number of cells, as typically only a small percentage of cells are degraded at end-of-life.[175] Remanufacturing is in its infancy, but industry interest is growing. Nissan produces remanufactured LIB for the Leaf, and various other OEMs have registered patents or announced future plans for remanufacturing.[176] EV Battery Solutions is a US-based startup, acquired by Cox Automotive Mobility in 2021, that partners with OEMs including Nissan and General Motors to provide 4R services (remanufacturing/refurbishment, repair, reuse and recycling).[177]

After 10 years EV batteries lose about 20% of their capacity and therefore have a SoH of 80%. LIBs are generally deemed unsuitable for use in EVs once they reach 80 or 70% SoH.[178] However, they are still suitable to be repurposed for 'second-life' in a range of applications that are less demanding. The most likely use for these batteries is for grid stationary energy storage applications, with potential lifetimes of up to 12 years.[179] They can also be used for low-power vehicles such as forklifts, buggies and ferries, although this is less economically favorable.[180]

[172] Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N., & Wang, Y. (2019). Recycling end-of-life electric vehicle lithium-ion batteries. *Joule*, *3*(11), 2622-2646.
[173] Castro, F. D., Cutaia, L., & Vaccari, M. (2021). End-of-life automotive lithium-ion batteries (LIBs) in Brazil: Prediction of flows and revenues by 2030. *Resources, Conservation and Recycling*, *169*, 105522.
[174] Kastanaki, E., & Giannis, A. (2023). Dynamic estimation of end-of-life electric vehicle batteries in the EU-27 considering reuse, remanufacturing and recycling options. *Journal of Cleaner Production*, *393*, 136349.
[175] Kampker, A., Wessel, S., Fiedler, F., & Maltoni, F. (2021). Battery pack remanufacturing process up to cell level with sorting and repurposing of battery cells. *Journal of Remanufacturing*, *11*, 1-23.
[176] Ibid
[177] EV Battery Solutions by Cox Automotive. (n.d.). Leading the world in end-to-end battery life cycle solutions. https://www.coxautoinc.com/ev-battery-solutions/#snt
[178] Canals Casals, L., Etxandi-Santolaya, M., Bibiloni-Mulet, P. A., Corchero, C., & Trilla, L. (2022). Electric Vehicle Battery Health Expected at End of Life in the Upcoming Years Based on UK Data. Batteries, 8(10), 164.
[179] Casals, L. C., García, B. A., & Canal, C. (2019). Second life batteries lifespan: Rest of useful life and environmental analysis. Journal of environmental management, 232, 354-363. Available online:https://lithium.sciencedirect.com/science/article/pii/S0301479718313124
[180] Dominish, E., Florin, N., Wakefield-Rann, R. (2021). *Reducing new mining for electric vehicle battery metals: responsible sourcing through demand reduction strategies and recycling*. Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. https://earthworks.org/resources/recycle-dont-mine/

Modeling of typical vehicle and battery use found that most EVs will reach end-of-life for reasons other than the battery performance. It is estimated most batteries will have a SoH higher than 75% at end-of-life, which suggests that the majority of EV batteries that reach end-of-life will be suitable for repurposing.[181]

However, it is important to note that the EV market will likely dwarf the stationary storage market, which will limit the benefit of this strategy. After the stationary storage market is saturated, batteries will need to be sent to recycling.[182]

The variation between battery design and chemistries limits remanufacturing and reuse by third parties. Therefore, repurposing of EV batteries for energy storage is likely to be initiated by original equipment manufacturers (OEMs) within a controlled, take-back system. [183] There are various examples of vehicle manufacturers exploring solutions to battery reuse, including Nissan's partnership with Sumitomo Corporation to reuse battery packs from the Nissan Leaf in stationary distributed and utility-scale storage systems[184], Renault Advanced Battery Storage Program which is the largest used EV battery installation in Europe[185] and BMW's partnership with Off Grid Energy to supply them with second-hand battery modules to be adapted and create mobile power units from.[186]

Reuse of second-hand EVs

There is a growing resale market for second-hand EVs, but it is hampered by accessibility and by the uncertainty surrounding the condition and performance of batteries over time, which makes it difficult to price used EVs. The market lacks standard pricing models and indicators, making it hard to compare the capacities of different EVs.[187]

There are a range of businesses working to support the expansion of the used EV market. For example, The Good Car Company is an Australian social enterprise that aims to increase the accessibility of EVs in the Australian market, where there are predominantly new and luxury EVs available. This is done through the importation of pre-owned EVs from Japan and the UK, including quality checking, compliance and warranty.[188]

Increasing the availability of data including evaluations of battery health can provide assurance to second-hand buyers. In the US, Recurrent enables the resale of EVs through preparing battery reports for EVs to check battery range and performance[189] and produce extensive quarterly reports on trends in used EV pricing and inventories.[190]

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[181] Canals Casals, L., Etxandi-Santolaya, M., Bibiloni-Mulet, P. A., Corchero, C., & Trilla, L. (2022). Electric Vehicle Battery Health Expected at End of Life in the Upcoming Years Based on UK Data. Batteries, 8(10), 164.
[182] Ibid
[183] Dominish, E., Florin, N., Wakefield-Rann, R. (2021). *Reducing new mining for electric vehicle battery metals: responsible sourcing through demand reduction strategies and recycling*. Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. https://earthworks.org/resources/recycle-dont-mine/
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The importance of design and standards for enabling a circular economy

For EVs and batteries to be reused, they need to be designed to be repairable and durable.[191] Many EV batteries are not repairable, which could lead to the entire vehicle being scrapped from damage. There are reports of insurance companies having to write off electric cars with damaged battery packs, which can make up a significant portion of the vehicle's cost, due to difficulties in repairing them. Some automakers have been working to make battery packs easier to repair, such as Ford and General Motors; however, Tesla's new structural battery pack has been described as having “zero repairability”.[192]

Battery design is essential to enable remanufacturing and repurposing. Batteries need to be designed so they can be easily, safely and economically disassembled, tested and reassembled.[193] In addition, there are several key principles to enable recycling including: battery packs that are easy to open and remove cells from; large cells that could be easily dismantled to separate components including cathodes and anodes; the use of reversible adhesives and binders to simplify cell separation and recovery of materials; and avoiding the use of hazardous chemicals such as fluorine and per- and polyfluoroalkyl substances (PFAS).[194]

The standardisation of EV battery design would increase the potential for reuse, remanufacturing, repurposing and recycling at a scale that can make an impact on mineral demand.[195] Currently, EV batteries are designed by manufacturers and OEMs for specific vehicles, with different chemistries and formats, resulting in lack of standardisation and fragmentation of volume.[196] Intellectual property concerns are a major obstacle, and therefore there is a need for governments to require and/or incentivize OEMs to design their batteries for circularity, remanufacturing, and recycling.

A voluntary standard has been developed for using second-hand EV batteries for energy storage systems (ANSI/CAN/UL 1974 Standard for Evaluation for Repurposing Batteries).[197] The standard includes requirements for the sorting and grading process of battery packs, modules and cells that are intended to be reused.[198] However, this standard is not yet widely used. The EU funded CIRCUSOL project is currently working with the International Electrotechnical Commission (IEC) to develop standards that include repurposing of EV batteries, in line with the voluntary standard. As part of this they have developed technical guidelines that specify the procedures and requirements for performance and safety tests, and validation tests for direct reuse or refurbishment.[199] Batteries are also required to meet performance and safety standards in their new application. However, the installation and product standard requirements for energy storage systems can inhibit the use of repurposed EV batteries which do not comply. These standards could be updated to include the use of repurposed EV batteries or new standards developed.

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Expanding sharing to EVs

There is an obvious opportunity for using passenger vehicles more intensively as currently they are idle or underutilized for large parts of their lifespan.[200] It is estimated that across most of the world, cars are parked for 95% of the time.[201] In addition, most trips have low occupancy rates; for example, there is an average of 1.5 passengers per car for each trip taken in the US.[202]

Sharing of EVs has the potential to decrease the overall number of new cars required but this dependent on whether sharing changes car ownership rates, the number of trips taken and the impact on car and battery lifespans.[203]

There are a range of sharing models and platforms for passenger vehicles with different environmental impacts.

- **Car sharing** includes short-term car rentals, either from a business that owns a fleet of cars, or peer-to-peer (private car owners who can list their car as available for rent when unused). There is some evidence that sharing reduces car ownership, for example a meta-analysis of case studies from Europe found that 12 to 15 private cars are replaced by each shared car;[204] a study in the US found that for each car-sharing car on the road, between nine and 13 cars are taken off the road;[205] and an independent survey of members of Australia's largest carsharing organisation GoGet found that more than 60% of members had deferred the purchase of a private car since becoming a member.[206]

  EVs have a high potential for use in car-sharing services, as trips are often short.[207] Car sharing is most common in Asia and Europe, which account for nearly 90% of worldwide members.[208] New car-sharing business models are emerging with EV-only fleets, such as BlueSG in Singapore.[209] Peer-to-peer car sharing services are also encouraging the uptake of EVs, for example Turo is available in several countries, including Australia, Canada, the USA, and the UK,[210] and Eeve is an EV-only peer-to-peer car sharing start-up expanding across major cities in Australia.[211]

- **Ridesharing or carpooling** services connect drivers and passengers who want to take a similar trip, such as for commuting or for long-distance trips. Ridesharing can increase vehicle occupancy from current low rates and reduce the number of vehicles on the road. However, ridesharing can make car travel more attractive and reduce travel costs (as these are shared), which may result in a rebound effect that encourages new trips by car and shifts away from public transportation.[212]

- **Ride-sourcing or ride-hailing** services connect passengers with a driver who uses their private vehicle to provide a paid service via an app (some services allow multiple passengers to share a trip). Ride-sourcing is most likely to lead to an increase in the number of trips taken by vehicles and an increase in the distance travelled by vehicles (as drivers spend 40% of their time driving without a passenger).[213]

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Drivers may also be more likely to purchase or upgrade a vehicle to offer ride-sourcing services. Although ride-sourcing can replace individual car travel or connect passengers to public transportation services, it is more likely to encourage additional journeys and replace journeys that would otherwise be taken by active or public transportation.[214]

Large ride-sourcing platforms such as Uber, Lyft, Didi and GrabTaxi, have had slow rates of EV adoption.[215] Although vehicles are owned by contracted drivers rather than the businesses, many of these platforms have been encouraging drivers to switch to EVs. For example, Uber plans to shift to 100% EVs by 2030 in Canada, Europe and the US, and worldwide by 2040, through financial incentives for drivers.[216]

E-bike and e-scooter sharing

Bike-sharing schemes can promote cycling by offering access to bicycles to locals and tourists without requiring them to own or bring their own bike to the city. Various public and private e-bike and e-scooter schemes have been implemented, particularly in Asia and Europe, which can expand coverage and overcome difficulties such as hilly terrain. Most schemes operate in one of two ways: public schemes typically have docking stations that bikes are collected from and returned to with charging points, or there are private dockless schemes where bikes can be parked anywhere, with mobile battery charging.

Cities including Amsterdam and Paris have seen widespread adoption of e-bike and e-scooter schemes. These offer mobility as a service through a range of formats, such as monthly subscriptions and on-demand at an hourly rate. Although there is evidence e-bike and e-scooter schemes can improve public health, increase uptake of cycling, and potentially replace car trips and decrease vehicle ownership, there are challenges such as speeding and unsafe riding,[217] the need for new regulation[218] and dumping of bikes and scooters. In Paris and in various cities across China, competing dockless bicycle start-ups flooded cities with bicycles and scooters to attain market dominance, which have been abandoned as the start-ups went out of business.[219]

There is emerging research on the impact of e-bike sharing systems on overall mobility patterns and vehicle ownership. Research exploring the implementation of the first e-bike sharing system in Northern Poland found that bike sharing is competitive with carsharing, moped, and taxi services, and complements public transportation as a first/last mile supplement. However, there are barriers to usage particularly for suburban residents, including the need to transport children and long distances to docking stations.[220]

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Battery leasing and swapping

Battery leasing is an emerging model for EVs, e-bikes and e-scooters. In these models, a customer buys the vehicle and pays a monthly fee to lease the battery. For example, VinFast is a Vietnamese-founded EV company that offers a Battery Subscription Program where customers pay a monthly subscription fee and VinFast is responsible for battery repairs, maintenance, and replacement. [221] Nio is a Chinese EV manufacturer that offers a similar battery-leasing service, and in addition, runs battery-swapping stations in China and Europe, allowing drivers to swap depleted batteries for fully charged ones.[222] Gogoro is a Taiwanese company that runs battery swapping for scooters, mopeds and motorcycles (see Case Study).

Battery swapping also has potential for use in road freight. For example, Janus electric is an Australian start-up that plans to provide exchangeable batteries for electric heavy vehicles, which are able to be changed in four minutes.[223]

A key benefit of battery swapping is that batteries can be swapped in a quicker timeframe than charging. This can encourage the use of smaller batteries, as a major reason passengers prefer large batteries is because they don't need to be charged as frequently and battery charging is typically slow.

If shared vehicles and/or batteries are owned by a company and leased or rented to consumers, this increases the potential for maintenance and repair of vehicles and best practice battery management throughout their lifecycle, prolonging their life, and increases the likelihood of refurbishment, reuse and recycling of batteries at end-of-life.[224] Sharing of vehicles and batteries uses them more intensively, but this may not make a significant difference to lifespans, as a large portion of vehicle wear and battery degradation takes place regardless of whether the vehicle is in use.[225]

Car-sharing schemes to increase EV access for low-income neighbourhoods

Several US cities are implementing EV car-sharing services to increase the affordability and accessibility of EVs. These programs have been designed with an explicit focus on equity, seeking to ensure the benefits reach low-income neighbourhoods that are most affected by poor air quality from transport pollution and where the high costs of EVs are a barrier to adoption.[226]

For example, BlueLA is an EV car sharing service in Los Angeles that includes a discounted membership rate for low-income residents. The program began in 2018 as a pilot of EV car sharing in low-income communities, through a partnership between the City of Los Angeles and Blink Mobility and supported by a grant from the California Air Resources Board and California Climate Investments. The LA Mayor's Office of Sustainability, the Shared Use Mobility Centre and other community-based organisations also support the project.[227]

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Co-benefits

- **Reduced emissions:** Second-life applications can help reduce emissions in the energy transition, for example, one study found that extending the life of EV batteries and utilizing off-peak low-cost clean electricity through battery re-use could double the GHG benefits of vehicle electrification.[228] Car sharing and ride sharing may also reduce emissions, but ride sharing and ride sourcing may have the opposite effect of increasing emissions, congestion and air pollution as they can increase the number of trips taken by car and displace the use of public transportation.[229]
- **Increased access to low-emission transport:** EVs have high upfront costs but low ongoing operating costs. Car-sharing schemes may increase access to EVs as they allow the users to spread out the high upfront costs into the usage cost through their collection consumption of the service.[230] This has the benefit of increasing equity of access to EVs and the associated benefits for reducing air pollution. Battery-leasing models also reduce the upfront cost of an EV for consumers, as the cost of the battery is spread out over time.

Enablers

- **Regulation**: In most countries, there is a lack of clarity in the regulatory regime for end-of-life EV batteries. Existing legislation related to e-waste could provide a framework for regulating EV batteries, but there is a need for legislation that includes definitions, standards (including for design and repurposing), liability and remedies.
- **Changing economics:** A battery can be up to 50% of the cost of an EV, so reuse, remanufacturing or repurposing can capture some of this value. However, the falling cost of new batteries poses a challenge for the reuse of batteries, as the cost advantage of second-life batteries is estimated to decrease from 30-70% to 25% by 2040.[231] Economic feasibility may be a challenge for EV battery remanufacturing, depending on the battery design.[232]
- **Quality assurance:** A key challenge in the second-hand EV market relates to uncertainty around battery condition and performance in the absence of standard pricing models and difficulty in comparing capacities. Similarly for battery reuse, current methods for predicting the remaining useful life of a battery are inaccurate and there is a lack of standardised testing processes.[233]
- **New business models:** Leasing models where a company retains ownership of a battery may increase the likelihood of refurbishment, reuse and recycling of batteries at. Leasing models are more likely to be attractive to manufacturers as second-life markets become more stable and the residual value of batteries becomes more apparent.[234]
- **Changing perceptions of shared mobility:** Consumer preferences around car ownership are changing. In particular, Gen Z consumers are open to sharing their private vehicles and have a preference for EVs and smaller vehicles, with leasing being the fastest-growing form of ownership in this group.[235]

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CASE STUDY 4:

Gogoro battery swapping

Gogoro is a Taiwanese company that, in addition to producing a range of electric scooters, runs the world's largest battery swapping network for electric scooters, with 2,727 swap stations in nine countries for 47 different scooter models.[236] Electric two-wheelers produce up to 67% lower GHG emissions per passenger kilometer and are up to 93 times faster to refuel compared to other low-emission vehicles. They can also provide lower operating costs for riders and contribute to better overall air quality and sustainability in urban areas.

Gogoro GoStation is their battery-swapping station, developed with the aim of enabling the adoption of e-scooters in urban areas and helping to build more sustainable cities with better air quality.[237] It is a modular and scalable platform that can be installed in various locations, such as parking lots, gas stations, and convenience stores, to provide a convenient and accessible battery swapping service to electric scooter riders. The system allows riders to swap their depleted batteries for fully charged ones at GoStation's across the nine markets it currently operates within: Taiwan, France, Germany, Italy, Netherlands, Spain, Switzerland, South Korea and China.[238]

The GoStation network is also integrated with Gogoro's cloud-based software platform, which enables real-time monitoring of battery usage, remote diagnostics, and predictive maintenance. This allows Gogoro to optimize its battery swapping service and provide a seamless experience for its customers. They are also undertaking R&D into battery recycling.[239]

In addition, Gogoro has partnered with several companies to develop new initiatives including battery swapping pilots in the Philippines,[240] India[241] and Singapore,[242] partnerships with companies in Japan and Taiwan to develop new models of scooters[243] and a partnership in Indonesia for the production of batteries, vehicles and battery recycling.[244]

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PRINCIPLE 4:

Close the loop on battery minerals

Recycling can reduce the demand for new mining as it creates a supply of recycled metals that can be used for new battery manufacturing. Currently, only a small amount of the metals used in LIB manufacturing comes from recycled sources. Modeling shows that improving recycling of end-of-life EV LIBs can significantly decrease primary mineral demand, for example:

- Modeling of EV mineral demand has shown that recycling can significantly decrease the primary demand for certain materials by 2040. Efficient recycling with a 95% recovery rate has the potential to reduce demand by 25% for lithium, 35% for cobalt and nickel, and 55% for copper in 2040 compared to primary demand, which presents an opportunity to reduce the need for new mining.[245]
- Separate modeling of primary mineral demand by 2050 found that recycling becomes important around 2035. Direct recycling can reduce primary mineral demand for lithium, graphite, aluminium and manganese by more than 30% compared to baseline recovery rates.[246]
- Modeling found battery recycling has the potential to reduce the cumulative material demand for lithium by 2050 by up to 23%, 44% for cobalt and 38% for nickel and graphite.[247]
- In 2050, secondary material from EV batteries could potentially supply up to 80% of cobalt, copper and nickel, and 60% of lithium in scenarios for Catalonia, Spain.[248]

Although recycling is important to reduce primary metal demand, the impact will not be significant until the mid-2030s, once large volumes of LIBs from EVs reach end-of-life. For critical battery metals – including cobalt, lithium and nickel – end-of-life LIBs are likely to be the main source of recycled metals for battery manufacturing. However, there will only be small volumes of LIBs that reach end-of-life over the next decade which will be inadequate compared to the growing demand for EVs. Recycling is therefore unlikely to make a large impact on mineral demand until there are substantial volumes of EVs reaching end-of-life.[249]

For this reason, it is important that recycling is not the only strategy used to reduce mineral demand and that it takes place only after a battery has been reused and remanufactured as many times as possible. Investment is required early on to make sure appropriate collection systems and infrastructure are in place once batteries reach end-of-life.

The extent to which recycling will reduce demand is highly dependent on which process is used, so there is a need to focus on recycling processes with high recovery rates, and not just metals with higher economic value. In the short term a range of recycling processes will be needed, but direct recycling is a promising technology that avoids some of the environmental challenges of current methods. Design for circularity is needed for batteries entering the market now so they can be easily, safely and affordably processed when they reach end-of-life.

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High recovery rates of minerals from battery recycling

Although LIB recycling is a mature technology, typical processes do not extract the full value of the materials in the batteries.[250] The most commonly used processes only recover valuable metals such as cobalt and nickel at a quality suitable for battery manufacturing, and other metals such as lithium, aluminium and copper may be downcycled or lost during the process. [251]

Pyrometallurgical processes, which use high-temperature smelting to process cells, typically recover cobalt and nickel in a mixed metal alloy and do not recover lithium. Hydrometallurgical processes, which use chemical processes to extract metals after they have been sorted and mechanically pre-processed (shredded) can recover cobalt, nickel, lithium and manganese, as well as the copper and aluminium foils. Pyrometallurgical processes can also be combined with hydrometallurgical processes but will not typically recover lithium.[252] It is possible to recover all battery minerals at high rates above 90% through current pre-processing and hydrometallurgical routes or through direct recycling (see below).[253]

Hydrometallurgical processes have the benefit of higher-purity outputs, recovery of more materials, lower temperatures and lower GHG emissions compared to pyrometallurgical processes. However, they have higher costs and complexity because of the need for sorting and the complexity of the process.[254] Pyrometallurgical processes have the advantage of being able to process multiple battery chemistries and cell types, without the need for sorting, but have the disadvantage of high energy use, the emission of harmful gases, which need to be captured, and the loss of materials in the process.[255] All recycling processes and facilities need to continuously meet the highest possible labor and environmental standards.

Although materials can also be recovered for use in other sectors (downcycling), recycling at a grade that is suitable for use in battery manufacturing will also be required to make sure materials have an end-market and avoid a surplus of secondary supply. For example, it is projected that there will be more lithium in the EV battery waste stream in 2040 in Europe than there is demand for lithium in other sectors.[256]

Closed loop battery recycling integrated with EV manufacturing

Mercedes-Benz opened a factory in March 2023 in Kuppenheim, Germany, that uses a patented recycling process for used LIBs from electric and hybrid cars. The hydrometallurgical recycling process can recover up to 96% of the lithium, nickel, and cobalt used in the batteries, as well as some manganese and aluminium. The recovered materials will be fed back into the recycling loop to produce over 50,000 battery modules for new Mercedes-Benz models. The factory will initially process approximately 2,500 tonnes of batteries per year, with the potential to increase capacity to 5,000 tonnes per year in the future. The source of the batteries is test vehicles, start-up batteries, and possibly returns from the field, and the recycled materials will be used to create battery cells for new hybrid and EVs, as well as for stationary energy storage systems.[257]

[250] Gaines, L., Dai, Q., Vaughey, J. T., & Gillard, S. (2021). Direct recycling R&D at the ReCell center. *Recycling*, *6*(2), 31.
[251] Velázquez-Martínez, O., Valio, J., Santasalo-Aarnio, A., Reuter, M. and Serna-Guerrero, R., 2019. A critical review of lithium-ion battery recycling processes from a circular economy perspective. *Batteries*, *5*(4), p.68
[252] Gaines, L., Dai, Q., Vaughey, J. T., & Gillard, S. (2021). Direct recycling R&D at the ReCell center. *Recycling*, *6*(2), 31.
[253] Dominish, E., Florin, N., Wakefield-Rann, R. (2021). *Reducing new mining for electric vehicle battery metals: responsible sourcing through demand reduction strategies and recycling.* Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. https://earthworks.org/resources/recycle-dont-mine/
[254] Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N., & Wang, Y. (2019). Recycling end-of-life electric vehicle lithium-ion batteries. *Joule*, *3*(11), 2622-2646.
[255] Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., ... & Anderson, P. (2019). Recycling lithium-ion batteries from electric vehicles. *nature*, *575*(7781), 75-86.
[256] Abdelbaky, M., Peeters, J. R., & Dewulf, W. (2021). On the influence of second use, future battery technologies, and battery lifetime on the maximum recycled content of future electric vehicle batteries in Europe. *Waste Management*, *125*, 1-9.
[257] Mercedes Benz (2023, March 3). *Mercedes-Benz groundbreaking ceremony for battery recycling factory in Kuppenheim, Germany.* https://media.mercedes-benz.com/article/3af10452-84b2-4cfc-b5f4-7b5589881c84

Advanced recycling that meets rigorous environmental and labour standards

Direct recycling is a promising process under development that aims to recover battery materials while retaining their chemical structure. The result is a material stream that is suitable for use in manufacturing of new battery cells, in comparison to pyrometallurgical and hydrometallurgical processes which recover the individual metals.

Batteries are disassembled and/or shredded, then active materials in the cathode are collected and separated from other components, and then the degraded materials are restored to their original performance to replace lithium lost during the battery life (also called upgrading, regeneration, rejuvenation or relithiation).[258] There is also research underway into how cathode materials could be upgraded once they are recovered. A battery recycled 10 years in the future may have cathode formulations that are out of date and no longer in demand for manufacturing, as chemistries have been changing over time to become more efficient and use less cobalt. The ReCell centre, established by the U.S. Department of Energy (DOE) in 2019, has developed the concept of ‘upcycling’, so that chemical composition of cathode materials can be changed to a more desirable formulation.[259] The focus on direct recycling has been on recovery of cathode materials, but could also extend to electrolyte, graphite anode and binders.

The benefits of direct recycling include lower emissions and less pollution than traditional methods.[260] The cathode of a LIB contains the most valuable metals in the battery, and as direct recycling retains the crystal structure of the cathode materials it retains more of the economic value of the material.[261] However, the major challenge of the technology is that batteries need to be processed with others of the same cathode material chemistry which requires rigorous sorting and pre-processing.[262]

There are some industry demonstrations of direct recycling. OnTo-Technology in Bend, Oregon has patented and demonstrated direct recycling of LIBs and built cells using recovered cathode material.[263] Farasis Energy is a LIB manufacturer based in California that has also developed a direct recycling process and has been awarded United States Advanced Battery Consortium (USABC) contract to develop the technologies.[264]

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[258] Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N., & Wang, Y. (2019). Recycling end-of-life electric vehicle lithium-ion batteries. *Joule*, *3*(11), 2622-2646.

[259] Gaines, L., Dai, Q., Vaughey, J. T., & Gillard, S. (2021). Direct recycling R&D at the ReCell center. *Recycling*, *6*(2), 31.

[260] Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N., & Wang, Y. (2019). Recycling end-of-life electric vehicle lithium-ion batteries. *Joule*, *3*(11), 2622-2646.

[261] Ji, Y., Kpodzro, E. E., Jafvert, C. T., & Zhao, F. (2021). Direct recycling technologies of cathode in spent lithium-ion batteries. *Clean Technologies and Recycling*, *1*(2), 124-151.

[262] Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N., & Wang, Y. (2019). Recycling end-of-life electric vehicle lithium-ion batteries. *Joule*, *3*(11), 2622-2646.

[263] Sloop, S., Crandon, L., Allen, M., Koetje, K., Reed, L., Gaines, L., ... & Lerner, M. (2020). A direct recycling case study from a lithium-ion battery recall. *Sustainable Materials and Technologies*, *25*, e00152.

[264] Farasis Energy (2022). *Farasis Energy validates sustainable Direct Recycling process for lithium-ion batteries.* https://www.farasis-energy.com/en/farasis-energy-validates-sustainable-direct-recycling-process-for-lithium-ion-batteries/

Co-benefits

- **Reduced emissions and environmental impact:** Hydrometallurgical processing has lower emissions than pyrometallurgical processing and direct recycling has lower emissions again. Direct recycling uses less chemicals with less secondary pollution impacts,avoids the emission of toxic gases associated with pyrometallurgical processes, and requires fewer chemical inputs than hydrometallurgical processes.[265]
- **Reduced safety risks:** Recycling of LIBs can have safety risks if not managed appropriately, such as electric shock, explosion and fire, and contain hazardous chemicals. For example, fluorine is used in several battery components and can emit HF gas if exposed to air or burned.[266]

Enablers

- **Changing economics:** The economics of battery recycling is dependent on the recovery of high-value cobalt, but there is a shift towards lower cobalt or cobalt free LIBs which will reduce the profitability of pyrometallurgical and hydrometallurgical processes. As direct recycling retains more of the economic value of the cathode materials, it can enable the profitable recycling of low-cobalt EV batteries and could also make recycling of LFP batteries profitable.[267]
- **Policy**: The effectiveness of mineral recovery is currently hindered by the absence of robust economic incentives or policies mandating recycling and the utilization of recycled materials in batteries.[268] Product stewardship including extended producer responsibility (EPR) schemes can help to facilitate an efficient and scalable recycling program. EPR schemes aim to shift the financial burden of end-of-life products from local governments or municipalities to producers. Making producers financially responsible leverages investment in recycling, and when coupled with ambitious collection targets and mandates on recycled content it can drive closed-loop recycling. EPR can also drive design for circularity if fees are differentiated to reward producers based on whether their product is more durable, repairable, recyclable or contains more recycled content (see case study 5 for EU example).
- **Design for circular economy:** The ease and effectiveness of recycling processes depend largely on the design of battery cells and packs, and LIBs have not been designed with recycling in mind (see box on page 36 for more information).

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[265] Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N., & Wang, Y. (2019). Recycling end-of-life electric vehicle lithium-ion batteries. *Joule*, *3*(11), 2622-2646.
[266] Thompson, D. L., Hartley, J. M., Lambert, S. M., Shiref, M., Harper, G. D. J., Kendrick, E., Anderson, P., Ryder, K. S., Gaines, L., & Abbott, A. P. (2020). The importance of design in lithium-ion battery recycling – a critical review. *Green Chemistry*, 22(20), 6842-6862.
[267] Gaines, L. (2019). Profitable recycling of low-cobalt lithium-ion batteries will depend on new process developments. *One Earth*, *1*(4), 413-415.
[268] Dominish, E., Florin, N., Wakefield-Rann, R. (2021). *Reducing new mining for electric vehicle battery metals: responsible sourcing through demand reduction strategies and recycling.* Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. https://earthworks.org/resources/recycle-dont-mine/

CASE STUDY 5:

EU regulation to improve battery recycling and supply chain due diligence

The European Union has introduced new rules on the sustainability, performance and due diligence of batteries across the battery lifecycle. The Batteries Regulation was proposed in December 2020 to replace the existing Batteries Directive, and in late 2022, The European Parliament and Council announced they had reached a provisional agreement.[269] The new Batteries Regulation was entered into force in August 2023 and will introduce requirements for batteries starting in 2025.[270]

The regulation covers the entire battery life cycle, including design, production and end-of-life management, and applies to all types of batteries sold in the EU, including EV batteries and light means of transport (LMT) batteries, such as e-scooters and e-bikes. The key measures that are relevant to EV and LMT batteries include:[271]

- Mandatory minimum levels of recycled content to be used in new batteries. This rate will be initially set at 16% for cobalt, 6% for lithium and 6% for nickel in 2031 (eight years after the regulation comes into force), and the targets will increase to 26% for cobalt, 12% for lithium and 15% for nickel in 2036. Recycled content is defined as from manufacturing waste (excluding by-products that are already re-used in the production process) and post-consumer sources, and there will also be a requirement for the documentation of recycled content.
- Targets for the minimum recovery levels of materials from recycling waste batteries. For lithium, this is 50% by the end of 2027 and 80% by 2031 and for cobalt, copper, lead and nickel this is 90% by the end of 2027 and 95% by 2031.
- Obligations to introduce a risk-based battery due diligence policy for economic operators (i.e. businesses and other organisations who put batteries on the EU market), except for small- and medium-sized enterprises (SMEs). Due diligence is required for critical raw materials (cobalt, graphite, lithium and nickel) and need to address social and environmental risks. Key social risks include human rights, health and safety, and labor rights, and key environmental risks include water use, soil protection, air pollution, climate change and biodiversity. The policy should be based on internationally recognised standards and principles for due diligence (see footnote for list of specific policies).[272]
- A digital battery passport that provides information and enables tracing of batteries, a compulsory carbon footprint declaration and labels or QR codes with information on materials, hazardous chemicals, safe handling and end-of-life treatment options.

A number of factors were identified as important to the development of the regulations. Firstly, there have been significant advocacy efforts to bring about these regulations. Collaboration among stakeholders in the battery value chain, such as through the European Battery Alliance, has facilitated the exchange of ideas

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[269] European Parliament. (2022, December 9). *Batteries: deal on new EU rules for design, production and waste treatment.* https://www.europarl.europa.eu/news/en/press-room/20221205IPR60614/batteries-deal-on-new-eu-rules-for-design-production-and-waste-treatment

[270] European Parliament. (2023, August 17). *Circular economy: New law on more sustainable, circular and safe batteries enters into force.* https://environment.ec.europa.eu/news/new-law-more-sustainable-circular-and-safe-batteries-enters-force-2023-08-17_en

[271] *Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC.* (2023). https://eur-lex.europa.eu/eli/reg/2023/1542/oj

[272] This includes United Nations Guiding Principles on Business and Human Rights, the Ten Principles of the United Nations Global Compact, the United Nations Environment programme (UNEP) Guidelines for Social Life Cycle Assessment of Products, the International Labour Organisation (ILO) Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy, the Organisation for Economic Co-operation and Development (OECD) Guidelines for Multinational Enterprises, the OECD Due Diligence Guidance for Responsible Business Conduct and the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas.

and networking amongst civil society, regulators and industry. In addition to the environmental and social objectives, there was a drive to establish the EV and battery industry in Europe and ensure a level playing field as all batteries entering the market need to meet the same requirements.

A challenge for the legislation is setting targets high enough to reduce primary mineral demand and encourage the development of the recycling industry, balanced against providing a realistic timeframe for industry change. There are concerns from some groups that the regulations do not go far enough, for example the minimum recycled content levels.

The EU regulation can provide a blueprint for other jurisdictions. As the regulation addresses the whole lifecycle, from design to end-of-life, and includes social and environmental aims, it has the potential to create systemic change and facilitate better outcomes than if these elements were addressed separately.

PRINCIPLE 5:

Source minerals more responsibly

There are significant opportunities to reduce the demand for new mining. However, some mining will still be required, and mining for LIBs for EVs is already taking place and rapidly expanding. There is an urgent need for more responsible sourcing practices to avoid and minimize the risk of adverse social and environmental impacts for mining for EVs.

Critical to this is guaranteeing the right of FPIC for Indigenous Peoples and their right to self-determination for any activities that will impact their lands. However, this practice is usually poorly implemented and in most cases is defined by private companies rather than Indigenous Peoples, and is often not enforceable under national laws. HREDD policies are also crucial for companies to identify and address social and environmental risks in EV supply chains.

Other important practices include adhering to the most rigorous and protective regulations and standards, such as the Initiative for Responsible Mining Assurance (IRMA); paying a living wage and ensuring the rights and safety of workers in industrial mines; improving environmental monitoring and compliance at mine sites; establishing 'No-go zones' or moratoriums on mining in critical ecosystems and sacred places; and ensuring there are no reprisals, attacks or criminalization of human rights and environmental defenders, many of whom are Indigenous Peoples and/or women.

These strategies can help ensure the production of EVs to meet climate goals does not have the unintended effect of burdening communities, regions and ecosystems, many of which will be most impacted by climate change.

Free, Prior and Informed Consent (FPIC)

More than half of known reserves and resources of transition minerals are found on Indigenous People's lands.[273] The rights of Indigenous Peoples include the right to FPIC as outlined in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) and International Labour Organisation (ILO) Convention 169.[274]

FPIC requires that **consent** must be obtained from Indigenous Peoples for any activities undertaken on their land. Consent means the right to say "no," "yes," or "yes with conditions" to any proposed or existing project. This must be **free** – given voluntarily without coercion, intimidation or manipulation, in a process led by the affected community, **prior** to any activities being authorised or commenced, and communities must be **informed** through transparent, accessible, accurate information given in the local language and an appropriate format. Communities should be able to negotiate and make decisions using processes they determine to be appropriate, such as customary processes.[275] In the engagement stage, the information provided, the process of engagement and feedback should be documented and disclosed. If an agreement is reached it is important to establish a mechanism or process to manage grievances.[276]

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[273] Owen, J. R., Kemp, D., Harris, J., Lechner, A. M., & Lèbre, É. (2022). Fast track to failure? Energy transition minerals and the future of consultation and consent. *Energy Research & Social Science*, *89*, 102665.
[274] United Nations (2011). *United Nations Declaration on the Rights of Indigenous Peoples.* https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf
[275] Oxfam Australia (2010). *Guide to Free Prior and Informed Consent.* https://www.culturalsurvival.org/sites/default/files/guidetofreepriorinformedconsent_0.pdf
[276] Cultural Survival and First Peoples Worldwide, with support from the Securing Indigenous Peoples' Rights in the Green Economy (SIRGE) Coalition. (2023). *Securing Indigenous Peoples' Right to Self-determination: A Guide on Free, Prior and Informed Consent.* https://static1.squarespace.com/static/62cd7860272be4335685de88/t/650b105c830dca28a4ee35ff/1695223916300/FPIC+guide+sm_compressed.pdf

A key component of FPIC is the ability for Indigenous communities to veto or say "no" during negotiations over developments on their land, including mining. Indigenous communities should also be guaranteed the right to revoke consent at any point in the mine lifecycle. This right to say "no" goes beyond the types of consultation that mining companies are required to do under regulation in many jurisdictions.

It is critical that FPIC is implemented correctly but this is rarely the case. Even in countries which have ratified UNDRIP or the ILO Convention 169, the two key agreements regarding FPIC, local communities are not always able to exercise FPIC. For example, in Australia Traditional Owners who have been granted land rights under the Native Title Act (1993), are still unable to refuse a development.[277] In many cases, FPIC has been defined by the mining sector and private companies, and has not been done in a way that is considered appropriate by the affected communities.

Human rights and environmental due diligence (HREDD) of supply chains

Understanding the supply chain is the first step to understanding the risk of environmental impacts from mining for renewable energy technology manufacturers. Transparency in the supply chain is challenging owing to the complex supply chains and multiple actors, including mine operators, traders, smelters and component manufacturers. For example, although the majority of cobalt is mined in the DR Congo, most of this is processed in China where it is blended together during the refining process.[278]

HREDD is a process to for companies to identify and address social and environmental risks in the supply chain to ensure they do not adversely impact surrounding communities and the environment. The UN Guiding Principles on Business and Human Rights outlines four key components: identifying actual or potential human rights impacts that a company may directly or indirectly contribute to, taking action, tracking the effectiveness of actions and engaging and communicating with stakeholders.[279]

HREDD requires companies to be proactive in assessing their supply chains, to implement policies that commit to the highest environmental and human rights standards and to cascade their corporate commitments throughout their supply chain by including them in their Supplier Code of Conduct. Companies should also implement an effective grievance mechanism for impacted communities, workers and other stakeholders to address and remedy the harms caused by their supply chains and operations.

Rigorous regulations and standards

Mandatory regulations for respecting human rights and the environment are crucial for protecting ecosystems and communities near mining activities. Where mandatory regulations do not exist or are inadequate, voluntary standards can be a useful tool for purchasers of minerals.[280] The use of third-party standards is not a replacement for respecting local and international laws and do not fulfil the obligation of companies to undertake HREDD.[281] Where a company uses a voluntary scheme, this should be considered one data point as part of their broader HREDD process, as the obligation to conduct due diligence on its supply chain ultimately rests with the company.[282]

There are a large number of voluntary third-party sustainability initiatives and standards that apply to the mining sector, but these are not all created equally. These initiatives vary in their scope (e.g. mine site,

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[277] Jubilee Australia Research Centre (2023). *Greenlight or Gaslight? The Transition Minerals Dilemma for Australia.* https://www.jubileeaustralia.org/storage/app/uploads/public/645/2cc/90a/6452cc90a05b2016702864.pdf
[278] RAID and CAJJ. (2021). *The Road to Ruin? Electric vehicles and workers' rights abuses at DR Congo's industrial cobalt mines.* https://www.raid-uk.org/sites/default/files/report_road_to_ruin_evs_cobalt_workers_nov_2021.pdf
[279] United Nations (2011). *Guiding Principles on Business and Human Rights.* https://www.ohchr.org/sites/default/files/Documents/Publications/GuidingPrinciplesBusinessHR_EN.pdf
[280] Lead the Charge (2024). *An Assessment of Third-Party Assurance and Accreditation Schemes in the Minerals, Steel and Aluminum Sectors.* https://leadthecharge.org/wp-content/uploads/2024/02/LeadTheCharge-Assessment-06022024.pdf
[281] Heinz, R. Sydow, J. & Ulrich, F. *An Examination of Industry Standards in the Raw Materials Sector.* https://www.germanwatch.org/sites/default/files/germanwatch_abstract_an_examination_of_industry_standards_in_the_raw_materials_sector_2022-09.pdf
[282] SOMO: Centre for Research on Multinational Corporations (2023). *Ten reasons why the European Commission's proposed Critical Raw Materials Regulation is not sustainable – and how to fix it.* https://www.somo.nl/wp-content/uploads/2023/05/SOMO-position-paper-on-Critical-Raw-Materials-Regulation.pdf

processing plant, company or supply chain, and which environmental, social and governance considerations are included), the scheme governance (how the scheme is run and the level of transparency) and the level of assurance to demonstrate compliance (e.g. ranging from self-reporting or third-party auditing).[283]

A best-practice approach for responsible sourcing is a commitment to source from mines that adhere to stringent environmental and human rights standards with independent, third-party monitoring and assurance of compliance.[284] For a scheme to provide credible assurance to end-users it needs to have comprehensive performance criteria and a multi-stakeholder governance system, rather than being only defined solely by the mining industry or other affiliated corporate actors. Evaluations of mine sites (as opposed to at a corporate level) are considered best practice as this is where most significant issues occur. In addition, schemes should include meaningful participation of rights-holders' in auditing processes, have robust systems and quality control, requirements for corrective actions to address shortcomings in audits and robust grievance or complaints mechanisms to aid communities in accessing justice and remedy if violations occur.[285] The Initiative for Responsible Mining Assurance (IRMA) Standard for Responsible Mining is considered the most comprehensive mining standard, and is one of the only ones with equal co-governance from civil society and industry representatives.

Other key practices to ensure responsible sourcing include:

- Paying a living wage and ensuring the rights and safety of workers in industrial mines;[286]
- Improving environmental monitoring and compliance at mine sites, including rehabilitation at end of the mine lifecycle;
- Establishing 'no-go zones' or moratoriums on mining in critical ecosystems, sacred places, or other places where mining should never take place;[287]
- No reprisals, attacks or criminalization of human rights and environmental defenders, many of whom are Indigenous Peoples and/or women.[288]

Co-benefits

- **De-risking mineral supply:** In addition to the benefits to local communities and environments, responsible practices such as FPIC have the added benefit of avoiding future conflicts, which can cause delays, financial risks and reputational risks.

Enablers

- **Policy reform:** In most countries significant policy reform is needed. Depending on the context this could include: mandatory HREDD legislation; reform of laws regarding Indigenous Peoples' land rights to be consistent with FPIC; strengthening biodiversity legislation including 'no-go zones', and updating mining laws to improve transparency and corruption and to ensure mining companies take responsibility for mine rehabilitation. Policy reform is necessary in countries with plans to ramp up production and to 'fast-track' or 'streamline' mineral developments that are considered strategic, which could result in the relaxation of regulations and risks circumventing a meaningful FPIC process.[289]

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[283] Rutovitz, J., Dominish, E., Farjana, S., Northey, S., & Giurco, D. (2020). *Certification and LCA of Australian Battery Materials – Drivers and Options.* Report prepared for the Future Battery Industries CRC, Australia.
[284] Earthworks (2021). *Recharge responsibly: The Environmental and Social Footprint of Mining Cobalt, Lithium, and Nickel for Electric Vehicle Batteries.* https://earthworks.org/wp-content/uploads/2021/09/Recharge-Responsibly-Final.pdf
[285] Lead the Charge (2024). *An Assessment of Third-Party Assurance and Accreditation Schemes in the Minerals, Steel and Aluminum Sectors.* https://leadthecharge.org/wp-content/uploads/2024/02/LeadTheCharge-Assessment-06022024.pdf
[286] RAID (2023, March 29). *Workers at DRC's industrial cobalt mines pushed further into poverty.* https://raid-uk.org/workers-at-drcs-industrial-cobalt-mines-pushed-further-into-poverty/
[287] Jubilee Australia Research Centre (2023). *Greenlight or Gaslight? The Transition Minerals Dilemma for Australia.* https://www.jubileeaustralia.org/storage/app/uploads/public/645/2cc/90a/6452cc90a05b2016702864.pdf
[288] Business and Human Rights Resource Centre (n.d.). *Transition Minerals Tracker.* https://www.business-humanrights.org/en/from-us/transition-minerals-tracker/
[289] Owen, J. R., Kemp, D., Harris, J., Lechner, A. M., & Lèbre, É. (2022). Fast track to failure? Energy transition minerals and the future of consultation and consent. *Energy Research & Social Science*, *89*, 102665.

CASE STUDY 6:

Using public procurement to drive industry-wide change

Electronics Watch is an NGO that uses public procurement leverage to promote and protect the rights of workers in global supply chains. Established in 2015, the organisation collaborates with civil society organisations and trade unions in production countries to monitor working conditions in mines and factories, and engage with industry to drive compliance and remedy.[290]

Its approach is to first support public sector organisations to incorporate contract conditions related to labour rights and safety standards into their electronics procurement contracts. The contract conditions require the supplier to establish transparency over their supply chain through due diligence, to work with independent monitors, and to remedy any breaches of the conditions.

The second step is monitoring for compliance, which is undertaken by an international network of local monitoring partners based in 18 electronics-producing countries. A core principle of the monitoring is to strengthen the voices of workers to report on problems in their factories and to empower them to drive the process. Electronics Watch monitoring efforts are driven by workers themselves, and ensure that their needs and perspectives are at the heart of remediation processes to address labour rights issues. The third step is for buyers, suppliers and workers' organisations to work together to investigate complaints and improve conditions.

Driven by demand from public buyers who have worked with Electronics Watch on electronics supply chains to expand the model to the automotive sector, the Low Emission Vehicles (LEVs) programme was launched in April 2022. Organisations participating in the program include Advanced Procurement for Universities and Colleges, UK; Barcelona City Council, Spain; Flemish Government Agency for Facilities and Operations, Belgium; City of Oslo, Norway; Transport for London, UK and Transports Metropolitans de Barcelona, Spain.

Electronics Watch is working with buyers to develop procurement tools that integrate criteria for workers' rights into the purchasing of LEVs, and some public buyers have already begun integrating the criteria into the tender process. The focus has been on the procurement of public e-buses.

Monitoring of the vehicle supply chains is focused on batteries, semiconductors and minerals. Worker-driven monitoring of semiconductor facilities takes place in Taiwan, Malaysia and China, and monitoring of battery factories began in 2023. There has been initial monitoring of minerals production including tin mines in Bolivia, cobalt mines in DR Congo, nickel mines in Indonesia and the Philippines and preparations for monitoring lithium mining in Bolivia.[291]

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[290] Electronics Watch (n.d.). *Contracting for Change.* https://electronicswatch.org/en/contracting-for-change_2548241
[291] Electronics Watch (n.d.). *Public Procurement of Low Emission Vehicles – Driving Social and Environmental Sustainability.* https://electronicswatch.org/en/low-emission-vehicles_2611904


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