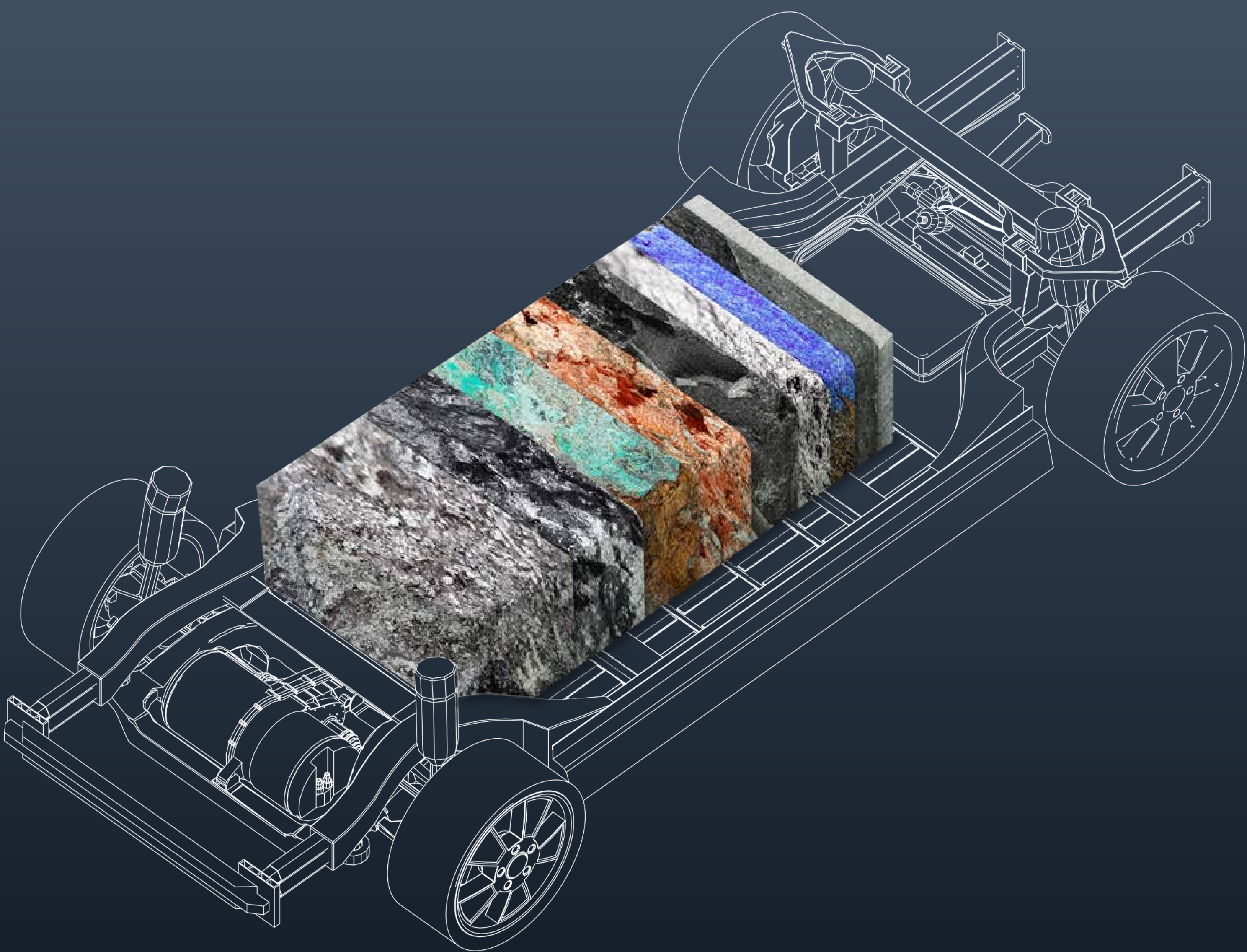
DRIVING CHANGE, NOT DEFORESTATION:

HOW EUROPE COULD MITIGATE THE NEGATIVE IMPACTS OF ITS TRANSPORT TRANSITION



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FRONT COVER:
Electric vehicles are powered by lithium-ion batteries, which use various minerals, including graphite, aluminum, nickel, copper, steel, manganese, cobalt, lithium and iron. Images from Shutterstock by cherezoff, The img, RHJPhtotos, Bjoern Wylezich, Zelenskaya, vvoe and Nanang Sugi.

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SUMMARY

BACKGROUND

The European Union (EU) aims to achieve climate neutrality by 2050, a goal central to the European Green Deal. The transport sector, responsible for nearly one-third of the EU's greenhouse gas (GHG) emissions, is a critical area for decarbonisation. With road transport contributing approximately 75% of these emissions, the transition to e-mobility is a necessity. This transition has accelerated the adoption of electric vehicles (EVs), which are expected to dominate passenger transport.

However, this necessary shift, if not adequately planned, comes with challenges. The increasing demand for electric passenger cars will drive a surge in the extraction of raw materials needed for batteries and electrical components. Mining activities for these metals pose significant environmental threats. Deforestation is one of the major concerns as it leads to biodiversity loss, ecosystem degradation, and carbon emissions. **This study assesses the future material demand for EVs in the EU according to assumptions regarding mobility trends and the associated deforestation footprint at the global scale.**

SCOPE OF THIS STUDY

This study evaluates the cumulative metal requirements and the associated deforestation impacts of the EU's transition to electric passenger vehicles from 2025 to 2050. It considers two main scenarios:

- **Business-as-Usual (BAU):** Business-as-Usual (BAU): continuation of current mobility trends with a mix of battery technologies.
- **Sufficiency Scenario (CLEVER):** transition incorporating increased carpooling, car-sharing, microcars, and a reduction in overall passenger kilometres.

Each of these scenarios includes two variations based on battery technology:

- **NMC 811 Battery Variant:** Assumes all new EVs use lithium-ion batteries with Lithium Nickel Manganese Cobalt Oxide (NMC) 811 cathodes, which are common in the European market but require significant amounts of nickel and cobalt.
- **LFP Battery Variant:** Assumes all new EVs use lithium-ion batteries with Lithium Iron Phosphate (LFP) cathodes, which do not contain cobalt or nickel and have lower deforestation impacts.

The study focuses on eight key metals used in EV production: iron, aluminium, copper, manganese, nickel, cobalt, lithium, and neodymium. It evaluates direct deforestation caused by the expansion of areas for mining iron, bauxite, copper, manganese, nickel, and cobalt.

FUTURE MATERIAL DEMAND FOR THE EU'S GROWING EV FLEET

Metal demand will peak by 2030 before slightly declining. The EU's yearly metal demand for EVs is expected to reach 24.5 million tonnes by 2030 before decreasing due to the longer lifespans of EVs.

Different battery technologies require different metals. In all scenarios, metals for the car body such as steel and aluminium make up the largest share of minerals. However, the choice of technology strongly influences the types of battery metals needed. NMC 811 batteries rely heavily on nickel and cobalt, whereas LFP batteries instead use iron and phosphate.

Sufficiency measures reduce metal demand. The CLEVER scenario, which includes shared mobility, smaller vehicle sizes, and reduced passenger kilometres, leads to significantly lower material demand compared to the BAU scenario.

DEFORESTATION FOOTPRINT OF THE EU'S GROWING EV FLEET

Under the BAU scenario, EV-related mining expansion could result in 65.2 thousand hectares of deforestation by 2050. If NMC 811 batteries dominate, deforestation could increase by 81% to 117.8 thousand hectares. In contrast, switching to LFP batteries could reduce deforestation by 43% to 37.3 thousand hectares. A CLEVER scenario, which combines sufficiency measures with LFP batteries, would decrease the deforestation footprint by 67% (compared to BAU) to 21.3 thousand hectares.

Battery technology plays a critical role in deforestation patterns. Batteries account for approximately 70% of the deforestation footprint of EVs, while vehicle bodies contribute only 30%. The type of battery used in EVs significantly affects deforestation levels. NMC 811 batteries, which require cobalt, copper, and nickel, are linked to high deforestation rates. In contrast, LFP batteries rely on materials with relatively lower deforestation intensity, such as iron, leading to a much smaller deforestation footprint. Further, different battery technologies rely on different metals and hence different sourcing countries. However, Indonesia and Brazil were identified as deforestation hotspots throughout the scenarios.

Sourcing strategies can mitigate deforestation impacts. The geographic origin of metals significantly influences deforestation. Three sourcing scenarios were analysed: (1) a **'Basecase'** Scenario, where metal sourcing follows historical trends, (2) a **'Forest at Risk' Scenario** with a higher share of metals from countries with high deforestation intensities, increasing deforestation risks by up to 266%, and (3) a 'Forest Protection Scenario' prioritising sourcing from low-deforestation countries, which could reduce impacts by up to 41%.

RECOMMENDATIONS

- **Promote sufficiency measures:** Limit battery and vehicle sizes, encourage car-sharing and public transport, and reduce car dependency.
- **Prioritise low-deforestation battery technologies:** Promote LFP batteries over NMC 811 batteries to reduce reliance on metals with high deforestation risks, such as nickel and cobalt.
- **Enhance recycling infrastructure:** Strengthen collection targets, encourage secondary metal use, and improve governance of the recycling industry.
- **Implement stricter mining regulations:** Establish 'no-go' zones for mining in protected areas, enforce third-party audits, and improve environmental standards.
- **Ensure responsible material sourcing:** Favour countries with lower deforestation risks and enforce strict due diligence in EV supply chains.

Reducing the size of electric vehicles, and importantly their batteries, could ensure a balance between affordability and environmental impact. Image: A small electric car charging, by Dizfoto/Shutterstock

Transitioning to electric mobility is a crucial step toward decarbonisation in the EU. The transport sector accounts for nearly one-third of all greenhouse gas emissions, mainly from road transport. Image: An electric vehicle charging, by Varavin88/Shutterstock

1. BACKGROUND

Achieving climate neutrality by 2050 is a central goal of the European Green Deal. To meet this objective, greenhouse gas emissions (GHGs) across all sectors must reach net-zero by mid-century (European Commission, 2019). The transport sector, responsible for about one-third of total EU GHG emissions, is a key area for decarbonisation, with road transport accounting for roughly 75% of the sector's emissions (EEA, 2024b). To reduce emissions, the EU introduced stringent carbon dioxide (CO_2) emission performance standards for passenger cars and vans (European Parliament and European Council, 2023a). From 2035, all newly registered vehicles in the EU must be zero-emission. Electric vehicles (EVs) are expected to dominate passenger transport due to their scalability and market readiness.

Although the EU has implemented policies to promote the adoption of EVs, there is notable political opposition within some Member States to abandoning the internal combustion engine. There is also opposition in the United States (US), where the Biden administration introduced measures to incentivise EV production and adoption. Critics argue that the transition could lead to job losses in the traditional automotive sector, and to an increased reliance on foreign supply chains, especially from China.

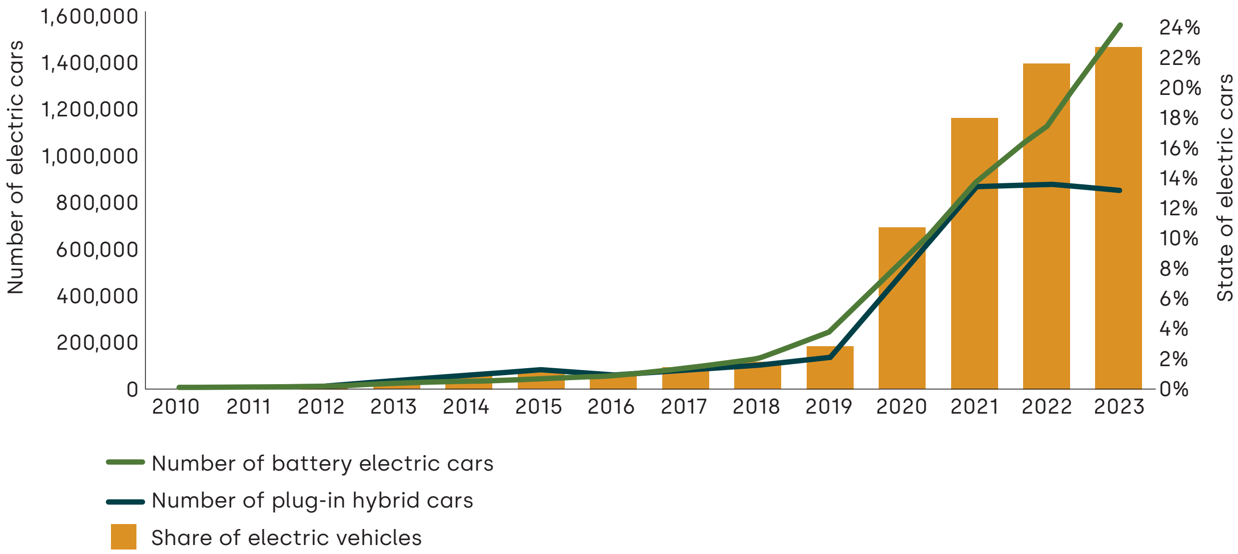
Nevertheless, the transition to EVs is ongoing and will increase the demand for a range of metals and industrial minerals to produce batteries and electrical equipment. As a consequence, mining of these raw materials will need to expand rapidly to satisfy the growing demand for electricity-driven mobility. However, the extraction of mineral resources has already become a significant driver of environmental impacts such as deforestation across a wide range of ecosystems with growing implications for land and water systems. As part of the required transition towards electric mobility, the expansion of mining should be implemented in a very responsible way, aiming at minimising the negative impacts for the local environment and population.

Against the background of growing EV fleets in Europe and across the globe, there is an urgent need to assess the environmental implications of the corresponding surges in material demand and to critically evaluate the options to transform the mobility system towards electrification. This study focuses on deforestation caused by the expected expansion of mining areas to extract materials for the production of vehicles that are mainly electric and consumed in the EU up to the year 2050. Deforestation was selected as a key topic, as it can serve as a proxy for a range of environmental concerns, including ecosystem integrity and biodiversity loss.

1.1 MARKET SHARES OF EVS IN THE EU

The adoption of EVs in Europe has accelerated significantly in recent years, although in 2024, the share of EVs in the sale of vehicles in the EU has decreased for the first time since 2020 (T&E, 2025). Annual sales increased from just 0.1 million units in 2016 to approximately 1.94 million in 2024 (Statista, 2024). By 2023, EVs – including plug-in hybrid electric vehicles (PHEVs) – constituted 23% of total new passenger car registrations in the EU (Figure 1). However, since 2021, registrations of EVs grew significantly faster than registrations of plug-in hybrid cars.

Figure 1 **Newly registered battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), and share of BEV and PHEV as a percentage of new car registrations in the EU-27**



Source: EEA, 2024a

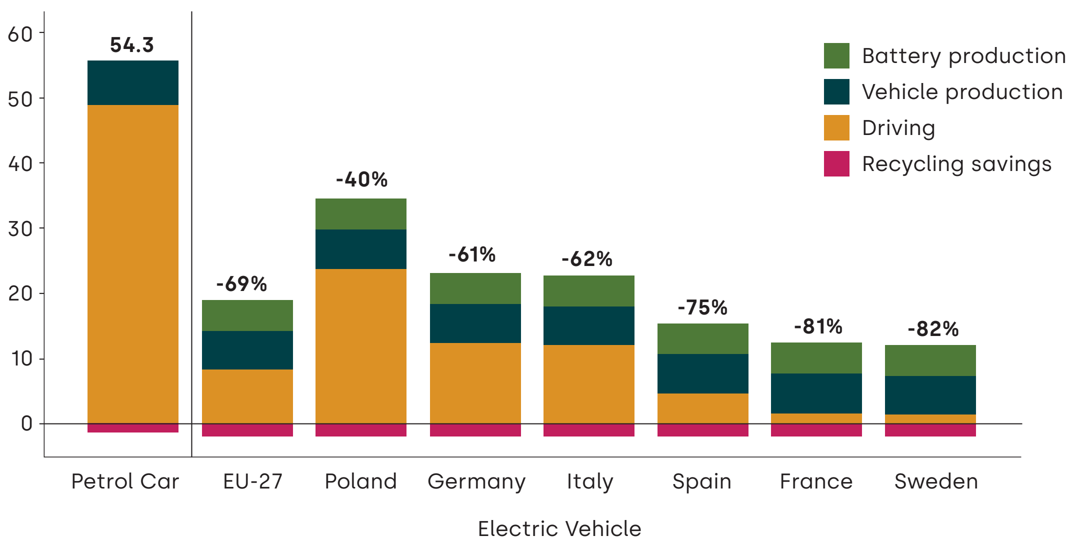
The decarbonisation of the transport sector is crucial for meeting the EU's net-zero commitment by 2050. Regulatory measures as part of the European Green Deal play a key role in accelerating electrification. The Net Zero Industry Act (European Parliament and European Council, 2024) aims to scale up the production of clean technologies, including EVs and their components. The data also shows that in the past few years, increasing consumer demand reinforced the transition to EVs across the EU.

1.2. CO_2-FOOTPRINT: COMBUSTION ENGINES VS. ELECTRIC VEHICLES (EVs)

EVs typically generate lower CO_2 emissions across their lifecycle compared to internal combustion engine vehicles (EEA, 2018). However, the calculations on EVs' emission reductions depend on factors such as vehicle size, battery technology, lifetime mileage, technology used for extraction of critical minerals, and the electricity mix used during driving.

For example, the European Environment Agency (EEA, 2018) estimates that EVs produce 17–30% fewer lifecycle emissions than petrol-powered cars, while Transport & Environment (T&E, 2022) suggests emissions reductions of up to 69% (Figure 2). Although EV production emits more CO_2 than production of conventional vehicles, this is offset by significantly lower emissions during the use phase, especially as the EU transitions to a renewable energy-dominated electricity mix (EEA, 2018).

Figure 2 **Life cycle emissions for EU electric cars compared to petrol cars**



Analysis of a medium-sized car; Recycling savings apply to the production phase. Source: T&E, 2022

Figure 2 also shows that the overall CO_2 balance of EVs is highly dependent on the energy mix used to generate electricity. In countries such as Poland, where coal makes up 60% of the electricity mix, the lifecycle emissions of EVs are significantly higher than in Sweden, which produces 70% of its electricity based on renewable energy sources, such as hydropower and wind. To fully realise the climate benefits of EV adoption, a shift to renewable electricity production is therefore essential.

Whether the car is electric or fossil, the vast majority of metal used will be for the car body. Copper and nickel are, however, mainly needed for the battery and electrical components. Image: Copper bars at a smelter, prepared for rail transport, Poland, by Dziurek/Shutterstock

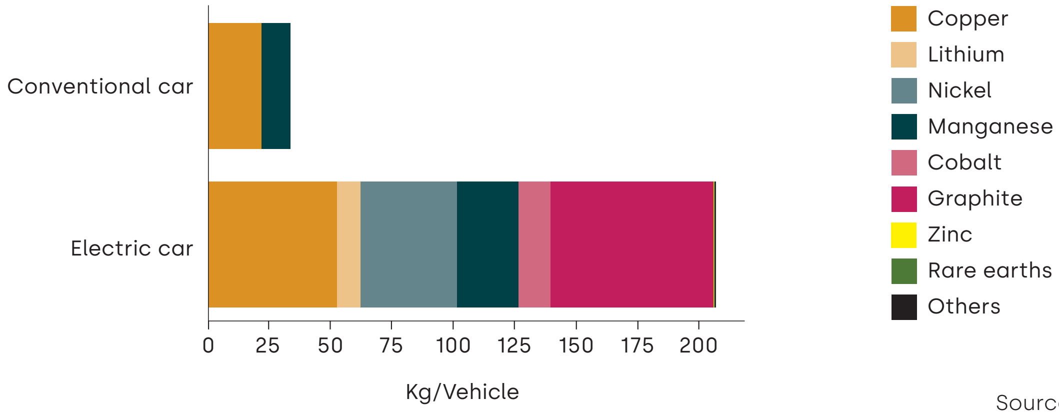
1.3. EVS' DEMAND FOR CRITICAL RAW MATERIALS

The shift to EVs significantly increases demand for various critical raw materials (CRM)[1] essential for battery production and motors. According to the International Energy Agency (IEA, 2022b), EVs require approximately six times more critical raw materials than conventional cars (Figure 3), excluding common materials like steel and aluminium that are used for producing car bodies and are therefore used similarly to produce conventional cars and EVs.

The demand for copper in EVs is, on average, more than double that of conventional cars, primarily due to the electrical components and cables. Additionally, the production of battery cathodes and anodes requires materials such as lithium, nickel, cobalt, manganese, and graphite. For example, an EV typically requires around 66 kg of graphite, 53 kg of copper, and 40 kg of nickel on average (IEA, 2022b).

1 We follow the IEA's definition of critical raw materials (CRMs), though definitions vary by author and time period. The 2023 EU study on CRMs excluded copper and nickel but included bauxite (aluminum ore), unlike the IEA's classification shown below. However, the Critical Raw Materials Act (European Commission (2024) now designates copper, nickel, aluminum, and 31 other materials as critical.

Figure 3 **Average critical raw materials demand for electric cars compared to conventional cars (excl. steel and aluminium)**



Source: IEA, 2022b

1.4. GROWING MATERIAL DEMAND BOOSTS MINING AND CAUSES DEFORESTATION

The growing material demand for both renewable energy technologies and electric mobility is expected to drive rapid expansion in mining activities (IEA, 2022b). In a net zero emission-future, in comparison to 2023, critical material demand is expected to triple by 2030 and quadruple by 2040 (IEA, 2024a).

It is acknowledged that agriculture is the primary driver of deforestation, accounting for around 90% of global forest loss (Pendrill et al., 2022). However, in the past few years, several studies have emphasised mining as an increasingly important cause. Despite its significantly lower numbers, mining plays a growing role. Mining activities are rapidly expanding, which will increase this sectors' role in the future. Mining is also particularly happening in biodiverse regions (Luckeneder et al., 2021) and on Indigenous lands (Owen et al., 2023). Mining can also have large-scale impacts in terms of pollution of soils and water.

Between 2000 and 2020, over 13,700 square kilometres (km^2) of forests were directly lost due to expansion of mining sites, with tropical and subtropical ecosystems among the most affected (Kramer et al., 2023). In addition to direct forest loss within mining areas - for example from expanding open pits, waste piles, or tailings storage - mines also induce indirect deforestation in their surroundings, as energy and transport infrastructure needs to be constructed and/or settlements grow (Giljum et al., 2022). This indirect deforestation can be an order of magnitude larger than the on-site effect (Sonter et al., 2017).

In recent years, critical materials have become an increasingly prominent driver of mining in many countries. For instance, nickel mining has evolved into a significant contributor to deforestation in Indonesia, with the nickel mining area growing by 700% between 2000 and 2020, from 49 km^2 to 375 km^2 (Heijlen and Duhayon, 2024). Although mining remains a relatively small driver of tree cover loss in the Democratic Republic of the Congo (DRC), it has led to the loss of 13,000 hectares of forests from 2001 to 2020 (WRI, 2024).

1.5. THE ENVIRONMENTAL IMPACTS OF MINING ON FORESTS

The extraction of mineral resources has become a major driver of environmental change, affecting a wide range of ecosystems with consequences for land and water systems that extend far beyond land cover change and deforestation. One of the most profound impacts is the loss of biodiversity. Forests are estimated to host 80% of terrestrial species (World Bank, 2019). Many mines operate in areas with high species diversity, such as tropical forests (Luckeneder et al., 2021). Their destruction results in direct habitat loss, threatening plant and animal species with extinction (World Bank, 2019).

There are also indirect impacts such as habitat fragmentation. For instance, globally, 27% of iron, copper, zinc, and aluminium mining takes place within a radius of 10 km of the borders of protected areas designed to protect biodiversity (Durán et al., 2013), and nearly all global nickel production is located within 20 km of protected areas (Luckeneder et al., 2021). Additionally, some mining operations happen in small islands with vulnerable ecosystems, moving pressures and impacts beyond the island's carrying capacity (JATAM, 2019).

Furthermore, forests serve as essential carbon sinks, playing a critical role in mitigating climate change. As some mining activities clear large forested areas, they contribute significantly to increased atmospheric CO_2 levels, thereby exacerbating climate change (Azadi et al., 2020; Mervine et al., 2025). The loss of carbon storage capacity is particularly pronounced in tropical rainforests, where mining operations often take place in the planet's most carbon-rich ecosystems (Giljum et al., 2022).

In addition to biodiversity loss and carbon emissions, the metal mining sector causes hydrological impacts. Particularly in water-scarce regions, mines can become the primary local water consumers, leading to conflicts with other users such as fishery, agriculture, and local communities (Holley and Mitcham, 2016; Ghorbani and Kuan, 2017). But mines can also affect water quality. For instance, mining can lead to soil degradation and erosion, as well as water pollution caused by acid mine drainage and the release of heavy metals, creating long-term challenges for environmental and human health (Macklin et al., 2023; Aska et al., 2024).

1.6 THE SOCIAL AND HUMAN RIGHTS IMPACT OF MINING IN FORESTS

Mining not only impacts the environment but also contributes to land conflicts. Indigenous Peoples and local communities have experienced land conflict, and water and air pollution as a consequence of extraction of minerals such as rare earths, nickel, cobalt, bauxite and gold. An increasing number of studies points to the impacts of extractive activities related to the energy transition on Indigenous Peoples (Owen et al., 2023) and human rights violations worldwide (Business & Human Rights Resource Centre, 2025).

Fifty four per cent of the transition minerals on the planet are found on or near Indigenous Peoples' territories. If peasant communities are included (many of which are Indigenous Peoples though not recognised as such), this figure rises to 70% (Owen et al., 2023). Mining also induces displacement and resettlements. Vulnerable communities are being displaced due to mining's expanding footprint on land and other natural resources on which these communities depend on (particularly water).

Mining waste is a big part of a mine's footprint so a significant contributor to this displacement. Mining causes both physical displacement (because the land on which people live is needed for mining purposes) and economic displacement (when people near the mine have to move because their sources of livelihoods have been compromised) (Owen et al., 2021). These human rights violations often occur in fragile states with severe water and food security conditions.

The Transition Minerals Tracker set up by the Business & Human Rights Resource Centre[2] recorded 630 human rights allegations related to extraction of transition minerals over the period 2010-2022. Minerals covered in the tracker include bauxite, cobalt, copper, lithium, manganese, nickel, and zinc.

Issues related to tailings or air pollution from coal-powered smelters are common human rights impacts faced by Indigenous Peoples and local communities. A Climate Risk Index (CRI) report (CRI, 2025), shows that nickel mining companies operating in Weda Bay Industrial Park (IWIP), Indonesia, are failing their human rights responsibilities under the United Nations Guiding Principles on Business and Human Rights, such as pollution problems, unfair compensations, health and safety issues, and loss of livelihoods - often paired with violence and intimidation. In nickel mining operations in Indonesia, community well-being declined (Lo et al., 2024).

1.7. GEOPOLITICS: TRADE AGREEMENTS AND COOPERATIONS

China dominates the global supply chain of Rare Earth Elements (REE), accounting for 70% of production and 90% of processing. China also dominates processing and refining of critical minerals (68% of the world's cobalt, 65% of its nickel, and 60% of the lithium of the grade needed for electric vehicle batteries) (Goldmansachs, 2023). Strategically, China has integrated fundamental research and technological advancement into their five years plan (Li et al., 2022), solidifying their leadership in battery technology. This geopolitical advantage means China has a quasi-monopoly position over global supply chains for advanced technology for batteries and EV battery production.

The global response to China's dominance on critical minerals global supply chain and EV battery technology has intensified, especially in the US. To secure its supply chains, the US established Mineral Security Partnerships (U.S. Department of State, n.d.) with the EU and countries such as Australia, Canada, India, Japan, Norway, the Republic of Korea, and the United Kingdom. Similarly, China has tightened strategic cooperation with Brazil, Chile, DRC and Indonesia- countries that have large reserves of critical minerals and rare earths. This geopolitical tension could intensify mining activities due to lack of international cooperation to address high critical minerals demands. The unintended negative consequences would further trigger deforestation and environmental degradation such as habitat and biodiversity loss, pollution and depletion.

The current geopolitical tensions have created EV trade barriers that might prolong and delay the required energy transition process. It is not yet clear what effects the US's April 2025 tariffs will have but the EU might require more time to reach its electrifications targets.

2 https://www.business-humanrights.org/en/from-us/transition-minerals-tracker

Deforestation occurs in mining areas when space is cleared for extraction and infrastructure, including processing facilities, and roads. Image: A nickel extraction site in East Sulawesi, Indonesia, by Erberto Zani/Adobe Stock.

2. SCOPE OF THE STUDY

This study evaluates the cumulative metal requirements and the associated deforestation impacts due to the expansion of mining areas for the EU's transition to electric passenger cars between 2025 and 2050. Our calculations are based on the assumption that the sales of petrol cars will fade out until 2035. Therefore, until 2035, a (declining) part of the material demand and related deforestation are related to petrol cars. Our work focuses on different scenarios for EV transitions and does not provide a comparative assessment between electric and petrol cars. The scenario was developed before 2025's challenges to EU agreements to phase out the combustion engine.

The study addresses the following questions:

- What are the raw material requirements of the various components of EVs under different scenarios?
- To what extent does material demand vary depending on different battery technologies and their future predominance?
- What is the amount of forest loss per tonne of extracted material used in the EV sector (deforestation intensity)?
- How do these deforestation intensities vary depending on the raw material's country of origin?
- What is the overall size of the global deforestation footprint linked to EU's future EV demand?
- How does the deforestation footprint change under different scenario assumptions, including technological aspects (different battery types) and sufficiency measures (for example, a reduction of passenger kilometres travelled)?

At times, indirect deforestation can far exceed direct deforestation occurring within mining areas. Image: A road to a nickel mine cuts through forest on Halmahera Island, Indonesia, by Forest Watch Indonesia.

2.1 METALS ANALYSED

This study assesses the cumulative metal requirements of EU passenger cars between 2025 and 2050. The following eight metals are analysed: iron (for steel production), aluminium (from bauxite ore), copper, manganese, nickel, cobalt, lithium, and neodymium. Lithium, cobalt, nickel and manganese are required to produce the lithium-ion batteries. Other crucial metals are used to produce EVs, such as iron, copper (for batteries, inverters, wiring and charging station) and aluminium extracted from bauxite (for chassis, frames, body panels and wheels). All these minerals can be found underneath forests (Kramer et al., 2023).

Note that lithium and neodymium were only considered in the metal demand scenarios, but not in the deforestation calculations. Lithium production from brine mining is located in non-forest locations and forest loss of mining from hard rocks, such as in Western Australia, is very small. For neodymium it was not possible to calculate specific deforestation intensities due to data limitations.

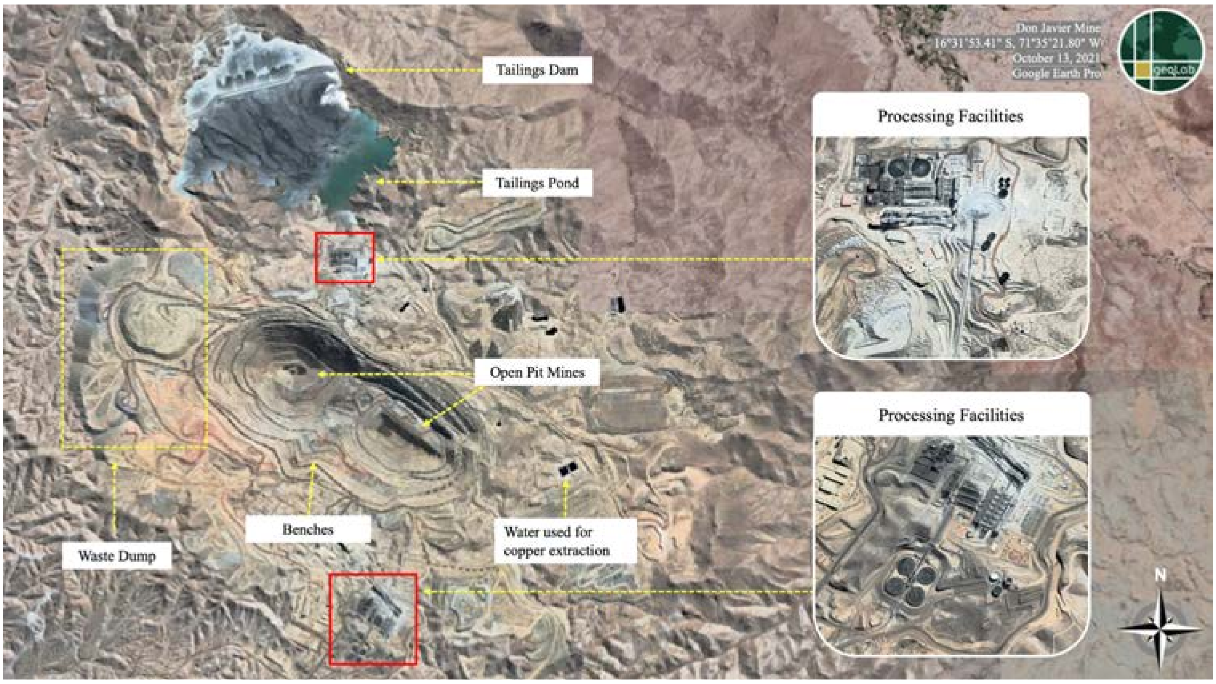
Since this report focuses on passenger transport, metal requirements for EV freight transport, as well as buses and two-wheelers, are excluded in terms of material and deforestation footprint – although they play a role in addressing mobility needs in the proposed scenarios. However, cars are still overwhelmingly the preferred mode of transport for Europeans. Between 2011 and 2019, car transport accounted for around 73% of passenger-kilometres across the EU (Eurostat, 2023). This mode of transport therefore plays a decisive role in determining the environmental footprint of mobility in Europe.

2.2 DEFORESTATION IMPACTS CONSIDERED

This study evaluates direct deforestation caused by the expansion of mining of iron, bauxite, copper, manganese, nickel, and cobalt. Deforestation is defined as the loss of forest cover in both temperate and tropical regions. Forests are classified as areas with vegetation exceeding five metres in height (for further details, see Section 6.3.1). Direct deforestation refers to forest loss occurring within mining areas, encompassing extraction sites and associated infrastructure directly used for mining, such as tailing storage facilities, waste rock dumps, on-site processing facilities and roads (see Figure 4).

Deforestation due to processing infrastructure that is not on-site, as well as indirect effects of expanding mining areas are not included in this analysis. Indirect deforestation refers to forest loss occurring in areas surrounding industrial mining areas. This can result from infrastructure expansion, such as building access roads for heavy machinery, settlement growth, or the conversion of land for agriculture. Assessing indirect deforestation effects is complex and requires a different approach than direct deforestation assessment. Consequently, indirect impacts are excluded from this study. Nevertheless, indirect deforestation is particularly pronounced in hotspot countries such as Indonesia and Brazil (Giljum et al., 2022). For example, in Brazil, the total mining-induced deforestation considering all commodities was estimated to be up to 12 times larger than the direct deforestation within mining areas (Sonter et al., 2017). Therefore, the actual extent of deforestation linked to mining for EVs in this study is a conservative estimation.

Figure 4: Don Javier copper mine in Peru



Don Javier copper mine in Peru.
Source: Moron et al. 2022

In recent years, European EV use has surged, increasing the demand for metals and minerals used in batteries and electrical equipment. Image: An industrial parking lot with new EVs in Belgium, by ambient_pix/Shutterstock.

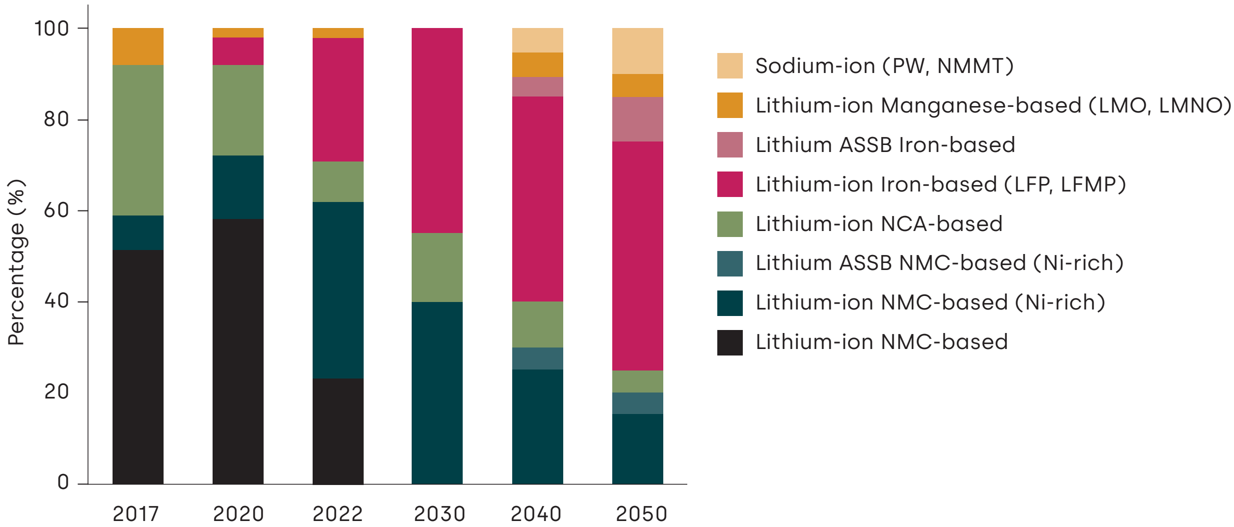
3. FUTURE MATERIAL DEMAND FOR EU'S GROWING EV FLEET

3.1 SCENARIOS AND ASSUMPTIONS

This study examines two main types of scenarios for the EU's future material demand: a reference business-as-usual ("BAU") scenario and a sufficiency-focused scenario ("CLEVER"). The key differences between the BAU and CLEVER scenarios lie in assumptions regarding mobility trends. In the CLEVER scenario, we assume an increase in carpooling, car sharing and in the share of microcars, as well as a decrease in the number of kilometres travelled by car in Europe and in battery size capacities (see Table 3 for main assumptions).

Both CLEVER and BAU scenarios are based on realistic assumptions regarding the use of different battery technologies in cars until 2050, reflecting current industry trends (IEA, 2022b; T&E, 2022; Ricardo, 2023; McKinsey, 2024). In 2050, this technological mix will include a significant proportion of lithium-ion iron-based (LFP and LFMP) batteries, around 20% of lithium-ion NMC batteries, and a small proportion of lithium-ion manganese-based, lithium ASSB iron-based and sodium-ion batteries[3] (Figure 5).

Figure 5 Evolution of the Eu battery technology mix considered in the business-as-usual and CLEVER Scenarios, 2017-2050



Source: Association négaWatt, based on IEA, 2022b; T&E, 2022; Ricardo, 2023; McKinsey, 2024

For both the BAU and the CLEVER scenarios, two variations of this technology mix are proposed: "LFP battery" and "NMC 811 battery". These variations focusing on just one battery technology are not intended to be realistic in themselves - such a clear-cut and rapid evolution of the market is unlikely - but are intended to test the deforestation impact of two different technologies that are currently dominant on the market.

The BAU and CLEVER "NMC 811 battery" scenarios assume that all new EV sales from 2025 onwards will use 100% NMC 811 technology, the battery chemistry common in the European EV market (IEA, 2024b). The purpose of this choice is to test whether the widespread use of lithium-ion batteries with NMC cathodes (Ricardo, 2023) in European EV passenger cars today is relevant from a deforestation perspective.

In contrast, in Asian EV passenger cars, lithium-ion batteries with an LFP cathode are more commonly used (IEA, 2024b). To investigate environmental impacts of different battery technologies, in the alternative "LFP battery" scenarios, it is assumed that from 2025 onwards, all new EV sales will be based on 100% lithium-ion batteries with LFP cathodes.

All scenarios follow the same assumptions regarding the proportion of recycled metal used in the body and battery and are aligned with current EU policies aimed at decarbonising the mobility sector by 2050. Figure 6 provides an overview of these six scenarios and their distinct assumptions.

3 Although considered a promising technology due to low costs, sodium-ion batteries still face challenges, in particular related to applications in high-altitudes and at very low temperatures (Qiu et al. (2024)). The potential for deforestation associated with sodium-ion technologies is not modelled in this report, as the production process of these technologies is still little known and the modelling results would be too uncertain.

Figure 6 Main assumptions for transport and battery capacity in the business-as-usual and CLEVER-scenarios, and the two variants

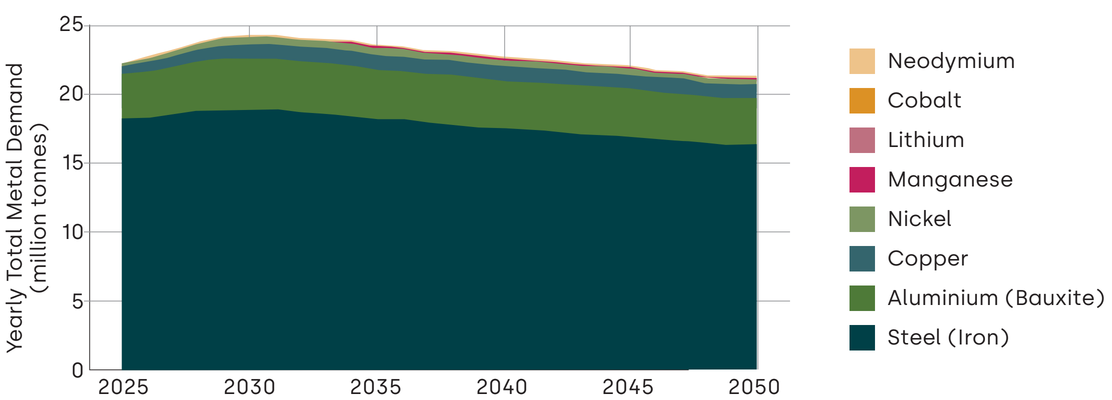
	Mix Battery prospective mix ensuring diversification based on nW research	NMC 811 Nickel Cobalt Less copper per kWh	LFP Nickel Cobalt More copper per kWh
Transport assumptions Increase of car transport demand Car sizes maintained Race for battery autonomy	BAU scenario	BAU NMC811 variant	BAU LFP variant
Transport assumptions Reduction of car demand, car pooling & modal shift Reduction of car sizes Adjusted battery autonomy	CLEVER sufficiency scenario	CLEVER NMC811 variant	CLEVER LFP variant

Source: Association négaWatt, own illustration.

3.2 EV METAL DEMAND

In a BAU scenario, average annual primary and secondary metal demand for EVs in the EU until 2050 will be at around 23 million tonnes per year. Figure 7 shows that material demand will increase from 2025 to 2030 (to a peak of 24.5 million tonnes) and then decrease from 2031 to 2050. The increase to 2030 can be explained by the switch to EVs, which are heavier and contain more metals than their petrol car counterparts, in particular because of the battery. The reduction after 2030 is a consequence of the longer life-time of EVs compared to their petrol-based counterparts.

Figure 7 EU's yearly metal demand for EVs in the business-as-usual scenario, 2025-2050

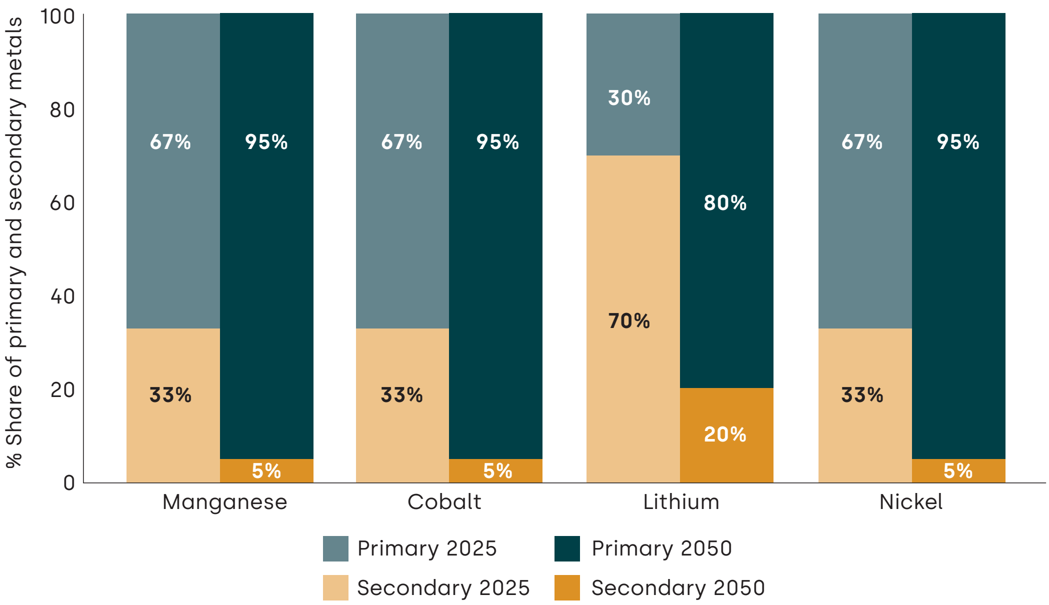


Source: own calculations, Association négaWatt

Growth in vehicle use drives overall metal demand, with bulk metals such as iron and aluminium remaining the most widely used metals in the automotive sector. Image: The underground iron mine of Kiruna in Sweden is one of the largest in the world, by Tommy Alven/Shutterstock.

For the calculation of potential deforestation due to EV metal demand, only primary metals, i.e. metals extracted in mines as opposed to metals produced by recycling are relevant. The share of primary and secondary metals in total metal demand varies by metal (see Figure 8 and methods section). All six scenarios are based on the same assumptions regarding the share of recycled metal used in the vehicle body and the battery. The assumptions about the share of secondary metals used in the automotive sector focus primarily on battery recycling (Figure 8). They are based on an ambitious interpretation of the Regulation on Batteries and Waste Batteries (European Parliament and European Council, 2023b), applying its targets while introducing a more ambitious modification, i.e. excluding the possibility of using metals in downcycling. The detailed assumptions underlying these results are outlined in the methodology section (Section 6.1.3). For metals used in components outside the EV battery cathode (e.g., the car body), all six scenarios follow a simplified and conservative approach, extrapolating historical trends to estimate future recycled content.

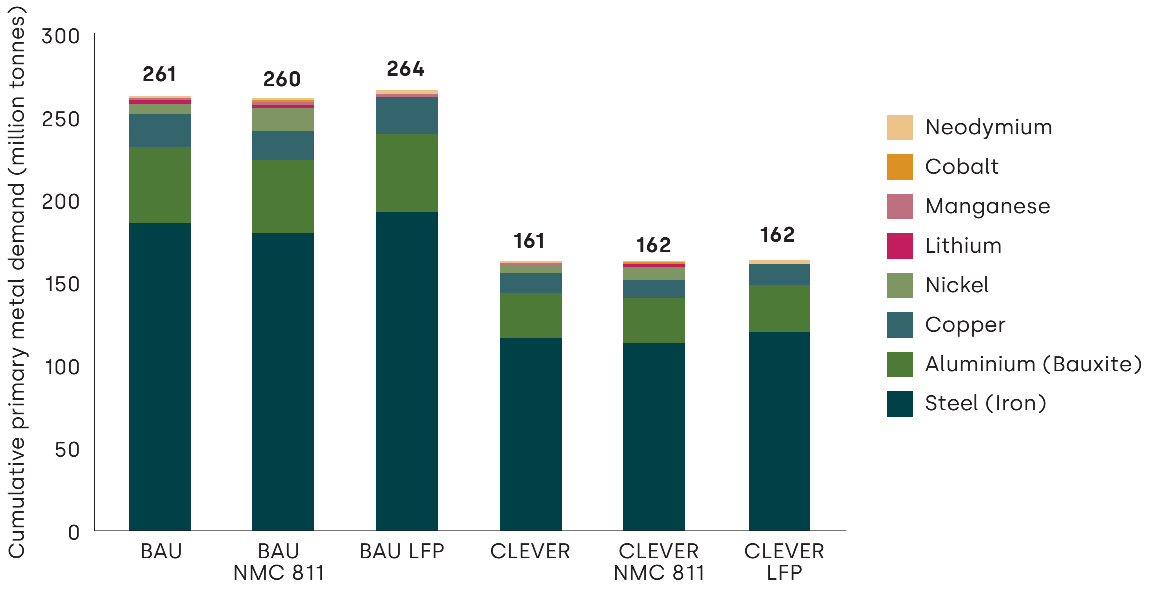
Figure 8 Shares of primary and secondary metals in yearly metal demand for car batteries in 2025 and 2050, by metals



Source: own calculations, Association négaWatt

In the following sections, only primary metal demand, which is relevant for deforestation, is considered. Figure 9 compares primary metal demand across the two different scenarios and their battery variations. In the BAU scenario, cumulative primary metal demand for EVs in the EU reaches 261 million tonnes by 2025. The battery variations have negligible impact on the total amount of metals, as steel and aluminium dominate the overall demand. However, the material composition changes, which we will further investigate below. In contrast, the CLEVER scenario demonstrates a significantly lower cumulative primary metal demand of only 161 million tonnes from 2025 to 2050. Again, material composition changes depending on the selection of either LFP or NMC811 battery chemistries.

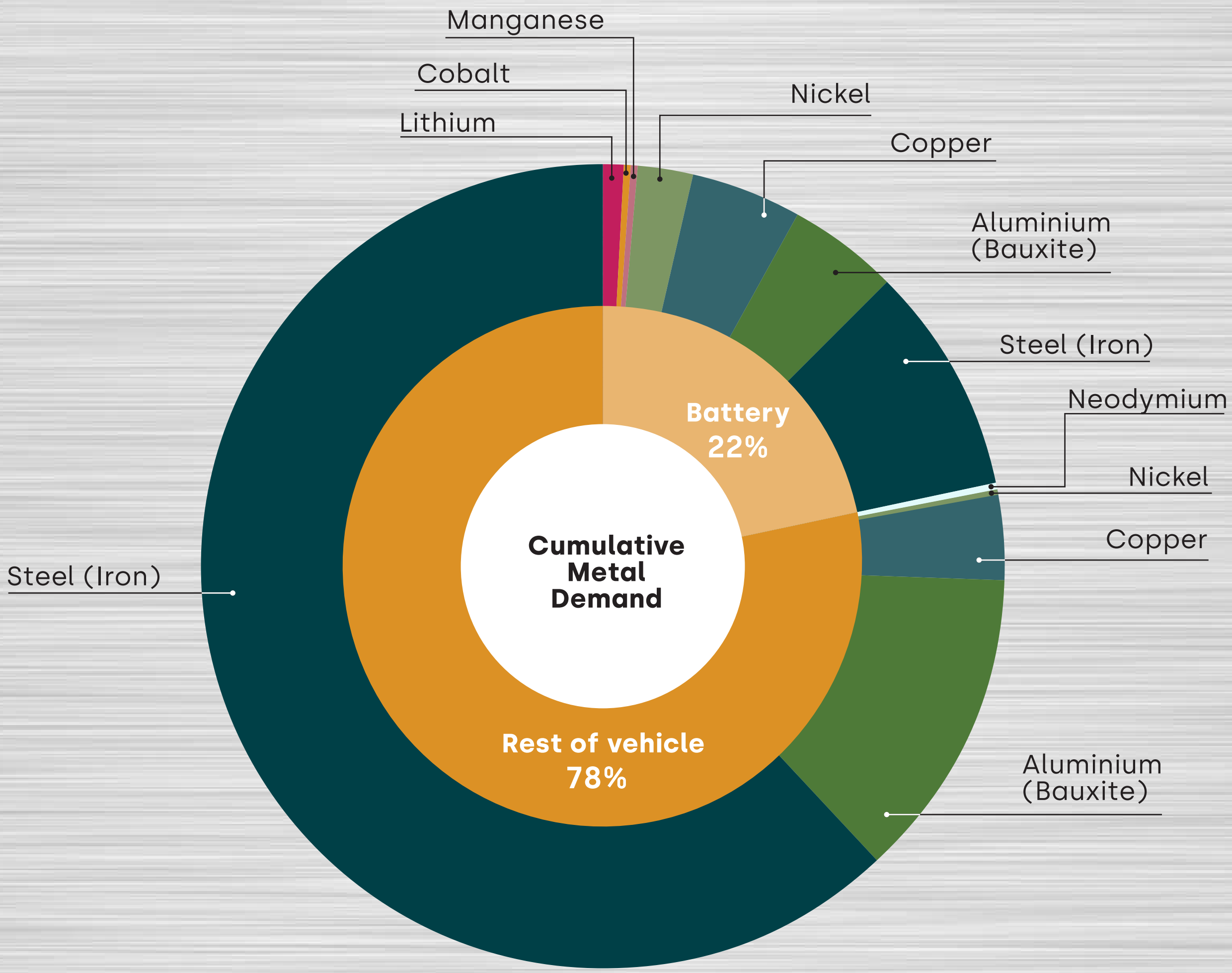
Figure 9 Cumulative primary metals required for passenger cars in the EU under different scenarios, 2025-2050



Business-as-usual (BAU): scenario with EVs with different battery technologies; "BAU NMC 811" scenario: scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "BAU LFP" scenario: scenario where all EVs have lithium-ion batteries with LFP cathodes; "CLEVER" scenario: mix of battery-powered vehicles, a general reduction in mobility, and a significant shift toward active transport modes and public transport; "CLEVER NMC 811" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "CLEVER LFP" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with LFP cathodes.
Source: own calculations, Association négaWatt

Overall metal demand is dominated by the materials required for manufacturing the vehicle body. In the BAU scenario, the share of metals for parts other than the battery is 78%, while the battery only contributes 22% to total metal demand (Figure 10). Across all six scenarios, steel accounts for the largest share – nearly three-quarters – of cumulative metal demand, followed by aluminium and copper. In fact, depending on the scenario, industrial metals (steel, aluminium and copper) make up between 93% and 99% of the total metal composition. While steel is almost entirely used for the vehicle body, copper and nickel are primarily needed for the battery and other components related to the vehicle's electrification (electric cables and motor). Aluminium is used mainly in the body but is also used to a significant extent in components related to electrification.

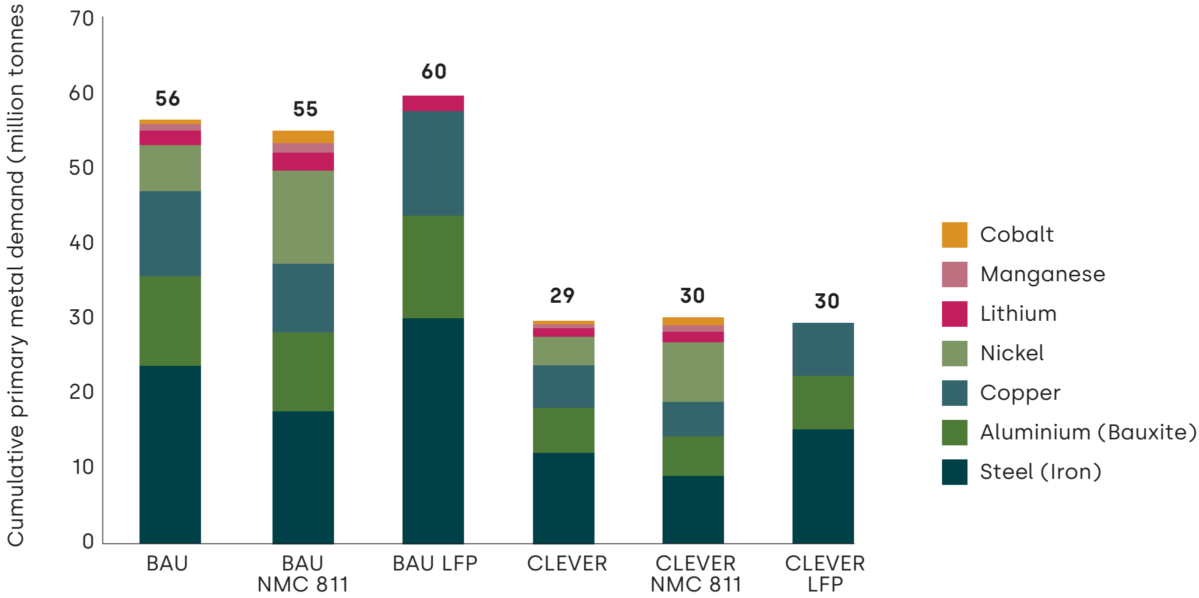
Figure 10 **Cumulative primary metal demand for passenger cars in the EU in the business-as-usual scenario, 2025-2050**



Source: own calculations, Association négaWatt

While metal demand for the car body is almost identical across vehicle types, metal demand for the battery varies significantly between the different scenarios (Figure 11). The LFP battery contains more iron and copper, but no nickel, cobalt, or manganese. In contrast, in the NMC 811 battery scenarios, these metals account for around 23% nickel, and around 3% of cobalt and manganese, respectively (for an overview of the material demand across all battery technologies, see Figure 25 in the methods section). The impact of electrification on metal demand is therefore most apparent regarding CRMs used in batteries, and less in the demand of other metals. Industrial bulk metals such as iron and aluminium remain by far the most widely used metals in terms of volume in the automotive sector in all scenarios, and fleet electrification has very limited impact on the demand of these metals. In this regard, growth in use of vehicles continues to be the main driver of overall metal demand.

Figure 11 **Cumulative primary metal demand for batteries in the EU under different scenarios, 2025-2050**



"BAU": scenario with EVs with different battery technologies; "BAU NMC 811" scenario: scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "BAU LFP" scenario: scenario where all EVs have lithium-ion batteries with LFP cathodes; "CLEVER" scenario: mix of battery-powered vehicles, a general reduction in mobility, and a significant shift toward active transport modes and public transport; "CLEVER NMC 811" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "CLEVER LFP" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with LFP cathodes.
Source: own calculations, Association négaWatt

Nickel and cobalt are frequently co-mined, and in some cases, by-products are the primary driver of mining operations. Image: A nickel extraction site in Indonesia, by Sesan13/ Shutterstock.

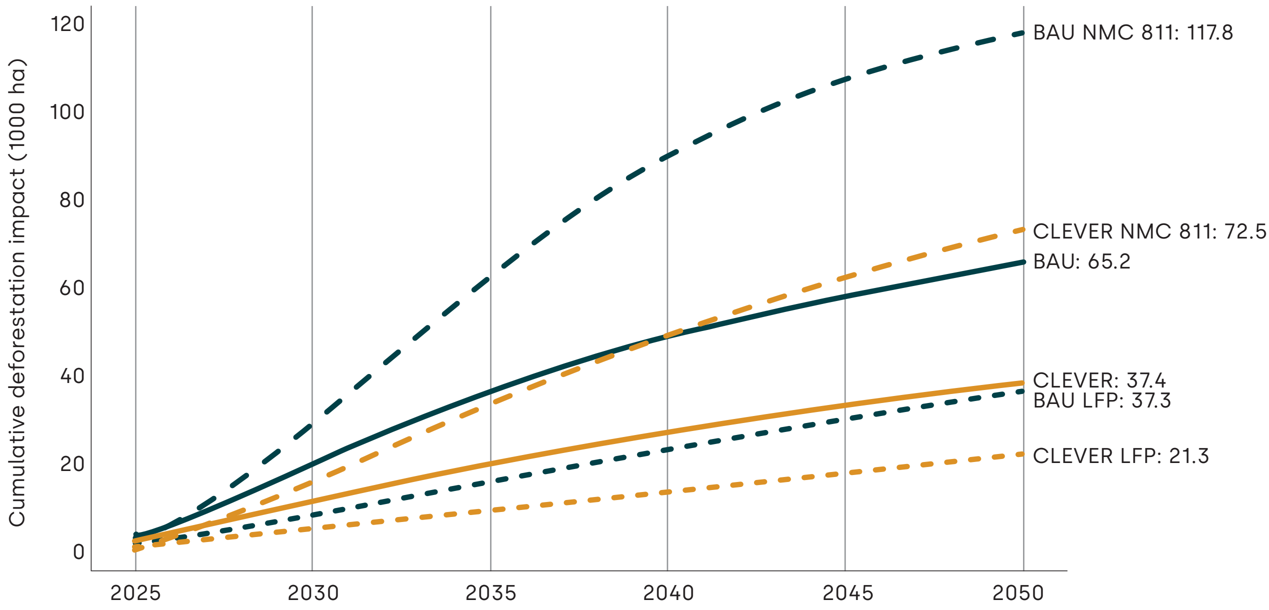
4. DEFORESTATION FOOTPRINT OF THE EU'S GROWING EV FLEET

The results related to metal demand presented in the previous section were used as the basis to calculate the deforestation risk associated with different scenarios. In this section, we present the overall deforestation potential across the six scenarios, investigate the differences between different battery technology choices and discuss the deforestation implications of sourcing the metals from different mining countries.

4.1 CUMULATIVE DEFORESTATION IN SIX EV SCENARIOS

The cumulative deforestation footprint from 2025 to 2050 varies significantly across the scenarios. Figure 12 shows that in the BAU scenario, cumulative deforestation potential amounts to 65.2 thousand hectares of world-wide forest loss until 2050. In a BAU-scenario variation where NMC811 batteries dominate EV-technology in Europe following current market trends (IEA, 2024b), cumulative deforestation could potentially cause forest loss of 117.8 thousand hectares until 2050 – a 81% increase in deforestation potential compared to the BAU scenario with a battery mix. Conversely, a shift to LFP battery technology could nearly halve cumulative deforestation to 37.3 thousand hectares compared to the BAU battery mix scenario.

Figure 12 **Cumulative deforestation for EVs in the EU under different scenarios*, 2025-2050**



* Out of the three different deforestation allocation scenarios considered, this graph refers to the Basecase scenario (see section 4.5 or 6.3.2)
"BAU": scenario with EVs with different battery technologies; "BAU NMC 811" scenario: scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "BAU LFP" scenario: scenario where all EVs have lithium-ion batteries with LFP cathodes; "CLEVER" scenario: mix of battery-powered vehicles, a general reduction in mobility, and a significant shift toward active transport modes and public transport; "CLEVER NMC 811" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "CLEVER LFP" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with LFP cathodes.
Source: own calculations, WU Vienna

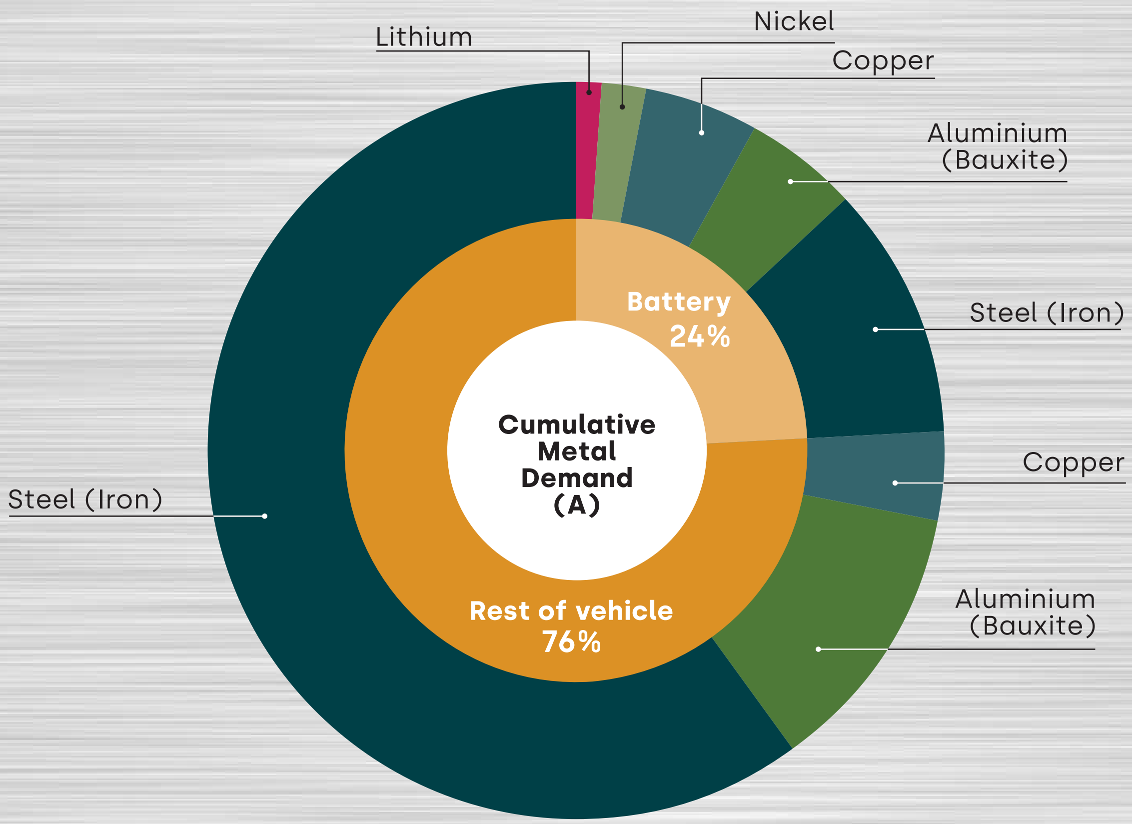
Under the CLEVER scenario, cumulative deforestation potential could drop to 37.4 thousand hectares, representing a 43% decrease relative to the BAU scenario. The CLEVER scenario of reduced passenger car mobility combined with only LFP batteries results in the lowest potential deforestation (21.3 thousand hectares).

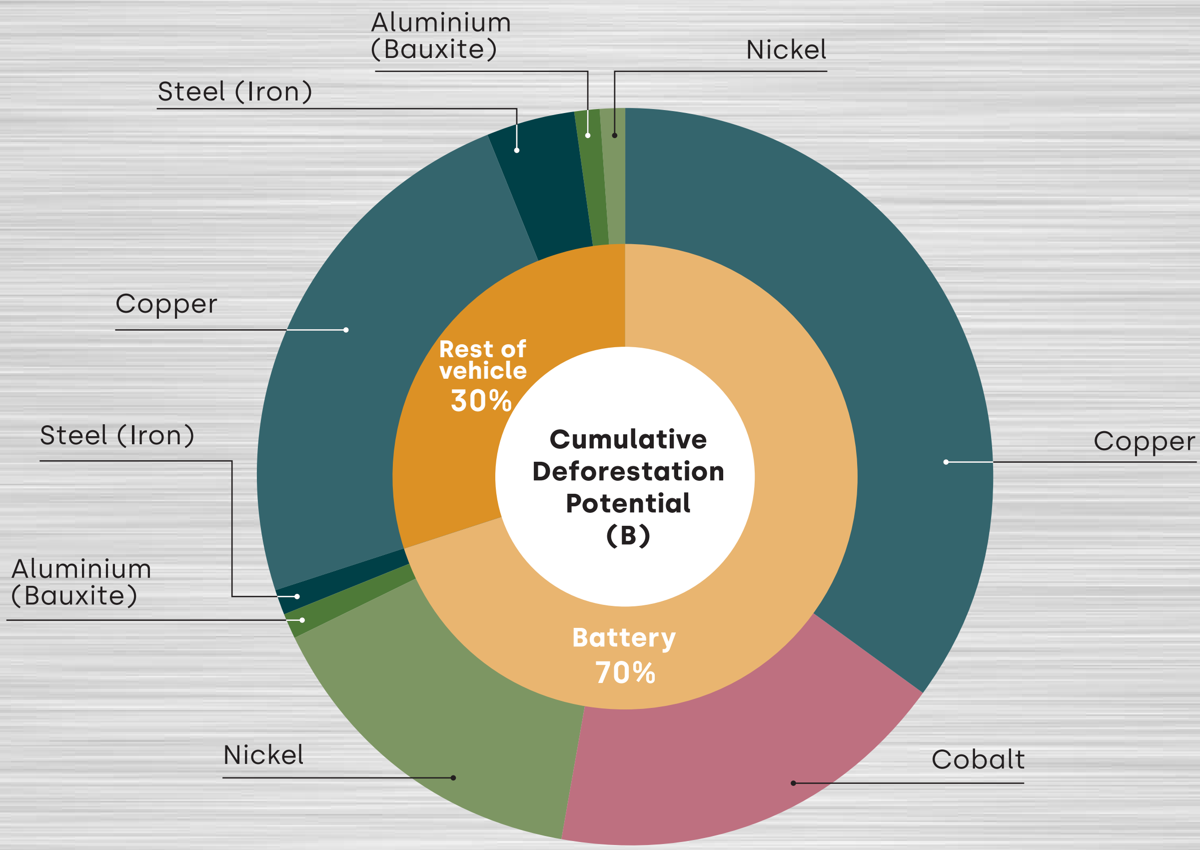
Although EVs offer significant environmental advantages over combustion vehicles in terms of lifecycle CO_2 emissions (see section 1.3 above), this first comparison already underscores that choices regarding battery technology selection as well as sufficiency measures play a substantial role for potential deforestation outcomes.

4.2 BATTERY TECHNOLOGY DETERMINES OVERALL EV DEFORESTATION POTENTIAL

In a BAU scenario, metals for EV bodies – primarily steel and aluminium – constitute the majority (76%) of the total cumulative EV metal demand from 2025 until 2050 (Figure 13A). However, when considering cumulative deforestation impacts, metals used in batteries account for the largest share (70%), whereas metals for the EV body contribute only 30% (Figure 13B). Hence, batteries rather than the car bodies determine the vehicles' deforestation impact.

Figure 13 **Comparison of cumulative primary metals required (A) and cumulative deforestation potential (B) for different materials in a business-as-usual scenario*, 2035-2050**





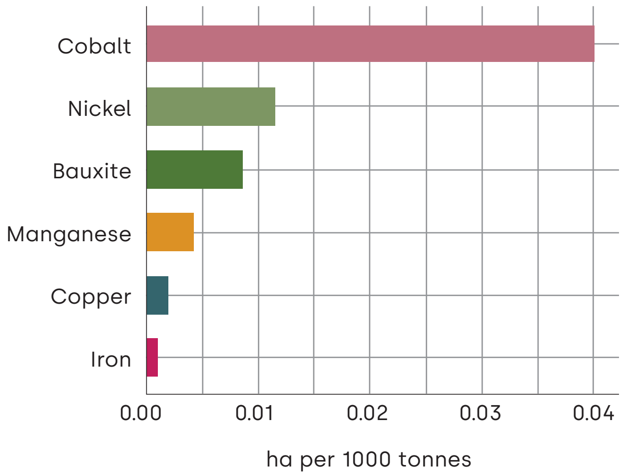
* Out of the three different deforestation allocation scenarios considered, this graph refers to the Basecase scenario (see section 4.5 and 6.3.2 below).
Source: own calculations, WU Vienna

Nickel and copper, which together make up only 10% of the total EV metal composition in terms of mass, account for 76% of the cumulative deforestation potential. Also cobalt, accounting for only 0.09% of the total EV metal composition, makes up 18% of the deforestation. This discrepancy arises because materials with the largest shares in terms of mass in EVs do not necessarily correspond to the highest deforestation impacts. Instead, deforestation impacts are primarily influenced by variations in deforestation intensities, which we will now investigate in more detail.

4.3 DEFORESTATION INTENSITY DEPENDS ON MATERIAL AND COUNTRY

The deforestation impacts of materials required for EV production vary significantly per tonne of material mined (Figure 14). On a global average, critical materials are associated with comparatively high deforestation impacts: for cobalt, the average value is around 0.04 hectares per 1,000 tonnes of primary extraction, for nickel it is around 0.01. In contrast, materials such as copper or iron on average are associated with significantly lower deforestation (around 0.002 and 0.001, respectively). These are, however, global average values that do not capture the substantial environmental impacts that. for example, iron mining can have in certain regions, nor do they account for other environmental effects beyond deforestation.

Figure 14 Comparison of average* deforestation intensities (hectares per tonne) for different materials, average 2000-2019



* Average refers to the global average weighted regarding production quantity of producing countries
Source: own calculations, WU Vienna

A NOTE ON THE CONSIDERATION OF CO-MINING (COUPLED PRODUCTION)

Many metals, such as nickel and cobalt, are often co-mined, i.e. the same tonne of crude ore extracted contains several metals. Since in some cases, by-products can also be the primary driver of mining activities, as is the case with nickel-cobalt mining in Indonesia, we allocate deforestation impacts to both the main product (nickel) and the by-product (cobalt). This double-counting of the same hectare of deforestation for all co-mined metals is later removed by scaling the total deforestation back to the national total. Through this procedure we ensure that forest loss across all mine-sites equals the national total deforestation, while all metal ores – and not just the primary products – are being recognised as a driver of forest loss.

The high variability in deforestation intensities can be attributed to several factors. Most notably, it depends on the ecosystem properties that surround specific mining sites, i.e. whether mines are located in forest areas, grasslands or desert ecosystems. Geological conditions also play an important role. For example, ore grades determine how much metal can be produced from a given quantity of extracted crude ore. Lower ore grades require more extensive mining and processing, leading to larger areas of land being cleared, which increases deforestation intensities. Additionally, laterally dispersed metal deposits, for example, cobalt and nickel deposits in Indonesia, require the clearing of larger forest areas, demand higher energy inputs and result in higher carbon emissions. In contrast, concentrated, vertical deposits may result in lower deforestation. Other contributing factors include predominant mining technologies, production quantities, and climatic conditions.

Open-pit mining (Figure 15) typically involves more extensive land clearing per unit of metal extracted than underground mining. Furthermore, large-scale industrial mining operations employing advanced machinery may reduce waste and improve efficiency compared to artisanal, small-scale mining (ASM), potentially lowering deforestation intensities.

Open-pit mining results in greater land clearing than underground mining. Image: A copper mine in Peru, by Jose Luis Stephens/ Adobe Stock

Mining in tropical regions with dense forests, such as the Amazon or Indonesia, results in significantly higher deforestation impacts compared to mining in arid or semi-arid regions such as the Peruvian Andes. Additionally, mining in remote areas often necessitates new infrastructure development, whereas metals mined in regions with established infrastructure require less land clearance.[4]

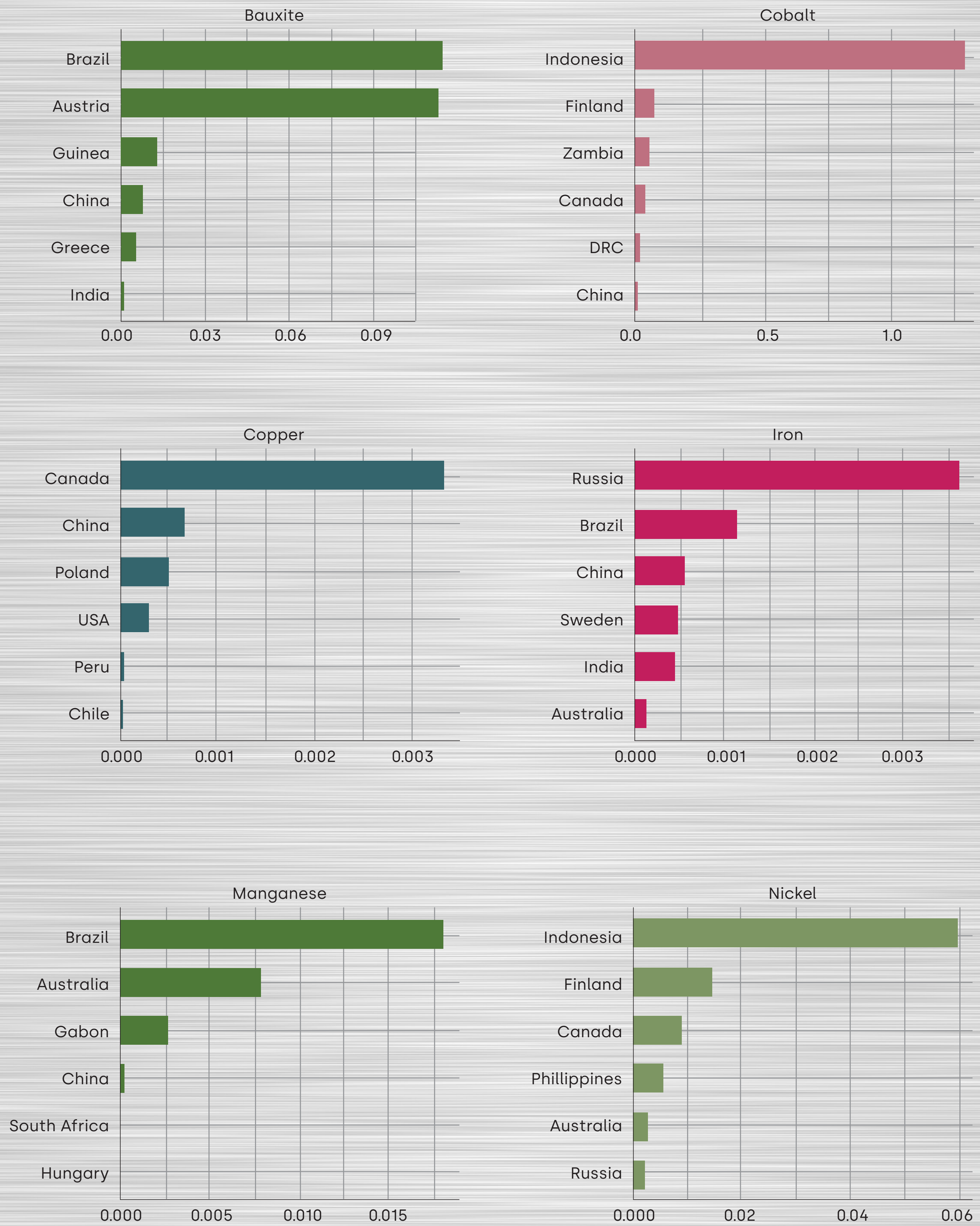
4 Note that in this study, indirect deforestation impacts are not considered (see section 2.2). Hence, deforestation for infrastructure is only included when installed within mining sites.

Tropical regions with dense forests experience significantly higher deforestation impacts due to mining. Image: A nickel extraction site in East Sulawesi, Indonesia, by Erberto Zani/Adobe Stock.

Furthermore, countries with strict environmental regulations and strong conservation governance regimes may enforce better land reclamation practices, reducing deforestation intensities, as studies on gold mining in Peru have illustrated (Schleicher et al., 2017; Dethier et al., 2023). Conversely, weaker enforcement in some countries may lead to more large-scale deforestation.

These variations also lead to significant differences in deforestation intensities between mining countries for the same raw materials (Figure 15).

Figure 15 **Comparison of deforestation intensities (hectares per 1.000 tonnes) for different materials and countries, average 2000-2019**



Source: own calculations, WU Vienna

For example, in the case of copper, mining in arid regions such as Peru and Chile results in lower deforestation per 1,000 tonnes of metal mined (0.00003 and 0.00001 hectares, respectively) compared to countries like Poland or China (0.0005 and 0.0007 hectares per 1,000 tonnes, respectively).

Similarly, for cobalt and nickel, deforestation intensities in Indonesia are 17 and four times higher, respectively, compared to Finland, indicating that significantly more land is cleared per tonne of material mined. With countries such as Indonesia specialising in the extraction and processing of energy transition minerals and expecting a significant growth in production, these differences have significant implications for forest ecosystems.

These differences can be partly attributed to geological factors and variations in vegetation. However, in regions with low deforestation intensity, mining may also contribute to other environmental impacts, such as water stress, and air and water pollution that are not captured in this assessment. For cobalt, methodological limitations also play a role. Expansion of cobalt mining in Indonesia began relatively recently, so deforestation intensities based on historical data up to 2019 are derived from a limited number of observations, leading to higher uncertainties and potential overestimations of the likely deforestation impacts of future cobalt mining.

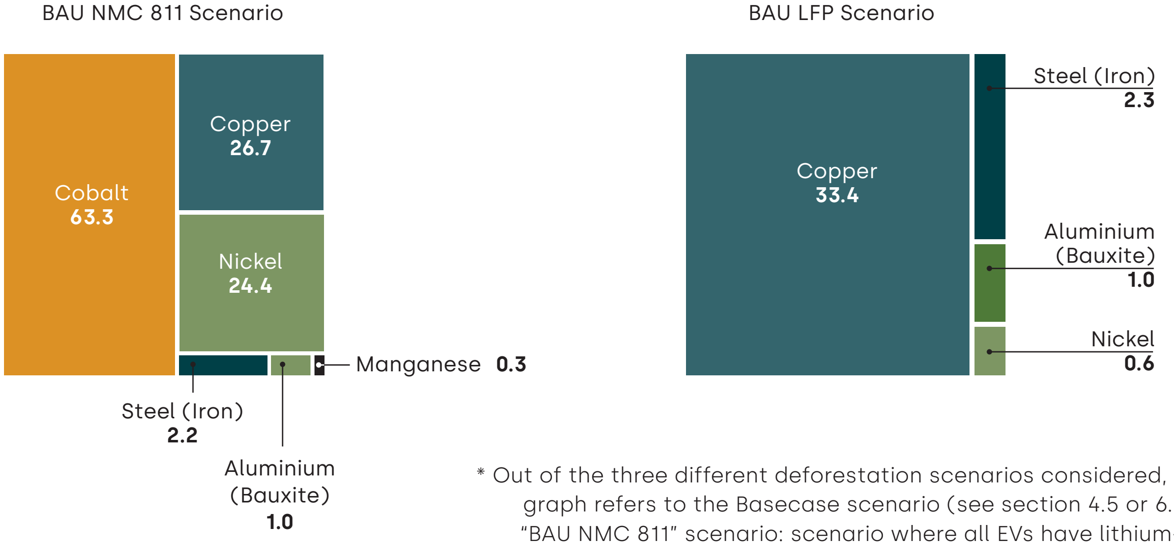
Additionally, there are considerable differences in deforestation intensities between different metals extracted within the same country. For instance, bauxite mining in Northeastern Australia's forests has a significantly higher deforestation impact per hectare than iron mining in Northwestern Australia.

4.4 BATTERY TECHNOLOGY MATTERS

Variations in deforestation intensities are particularly relevant when comparing the deforestation potential of different battery technologies, as they vary significantly regarding their material composition (see Figure 11 above and Figure 23 in the methods section). LFP batteries primarily depend on lithium, while NMC batteries require large quantities of nickel and cobalt (see section 3.2). As the required materials vary with regard to their deforestation impacts, the future dominant battery technology substantially determines potential deforestation impacts.

Figure 18 illustrates the share of different metals contributing to cumulative deforestation. In the BAU scenario where EVs from 2025 to 2050 are exclusively based on NMC 811 batteries, cobalt accounts for roughly half of the total cumulative deforestation, while copper and nickel each contribute approximately 25%. In contrast, under the BAU LFP scenario, deforestation numbers are much smaller and copper is responsible for nearly all deforestation impacts.

Figure 16 **Cumulated deforestation potential for BAU LFP and BAU NMC 811 battery scenarios* (1000 hectares), by metals, 2025-2050**



* Out of the three different deforestation scenarios considered, this graph refers to the Basecase scenario (see section 4.5 or 6.3.2) "BAU NMC 811" scenario: scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "BAU LFP" scenario: scenario where all EVs have lithium-ion batteries with LFP cathodes.
Source: own calculations, WU Vienna

This highlights that the choice of predominant EV battery technology in the future will significantly influence potential deforestation impacts. However, sourcing also plays a critical role. Some countries are deforestation hotspots with high intensities for a specific metal, while others have a much lower impact. Consequently, besides battery technology, sourcing decisions will have a substantial effect on the deforestation outcomes.

4.5 SOURCING MATTERS: DEFORESTATION ALLOCATION SCENARIOS

As deforestation linked to metal supply is inherently measured ex-post, future deforestation can only be modelled based on assumptions on the geographic distribution of future metal extraction. However, the global distribution of future metal extraction associated with EV demand depends on numerous variables, including geological, economic, technological, and political factors. To grasp the range of uncertainties, we estimate deforestation based on three different scenarios of future metal supply structures. These scenarios were based on a literature review, and a plausibility check was introduced through cross-checks with reserves data from the US Geological Survey. Note that the three scenarios are tentative frameworks intended to illustrate the potential environmental impacts of different sourcing strategies rather than providing precise forecasts for where mining activities will actually occur in the future (see Section 6.2 below for details).

- **The Basecase scenario** assumes that future material supply of the EU follows historical patterns. Therefore, the geographical distribution of metal supply is assumed to remain constant between 2025 and 2050.

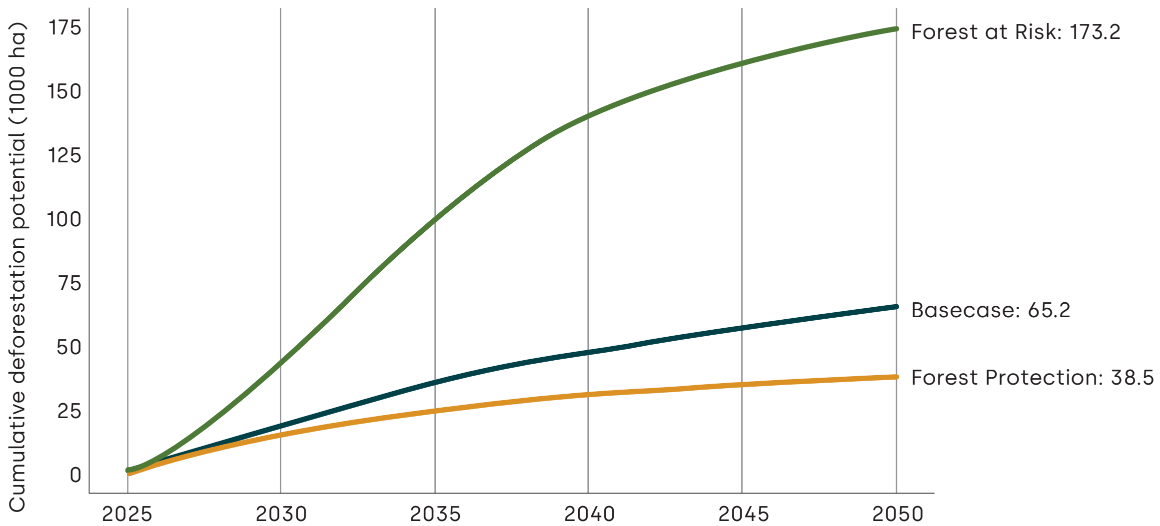
- **Forest at Risk scenario:** This scenario builds on the basecase scenario but examines the implications of a shift towards a supplier structure characterised by a high share of countries with high past deforestation intensities. For example, it is assumed that mining for nickel and cobalt in Indonesia will increase.

- **Forest Protection scenario:** This scenario builds on the Basecase scenario, but sourcing is shifted to countries with historically low deforestation intensities, examining the impact of sourcing practices which put a particular emphasis on avoiding future deforestation.

In the basecase scenario, we split the six investigated metal ores into two groups. For iron/steel, aluminium/bauxite and copper we assume that supply chain structures for EVs are similar compared to petrol cars and thus approximate the origin through the current supply structure for vehicles of all types sold in the EU. As China dominates the market for EV battery production, we assume that the origins of nickel, cobalt and manganese can be traced back by using Chinese import data.

Results for the three different scenarios on metal sourcing show that the geographic origin of materials can significantly influence deforestation outcomes. The BAU-Basecase scenario shows a deforestation potential of 65.2 thousand hectares (Figure 17) and is identical to the BAU number shown in Figure 12 above. In the Forest Protection scenario, deforestation is reduced to 38.5 thousand hectares (a decrease of 41%), while the Forest at Risk scenario shows a substantial increase to 173.2 thousand hectares (+266% compared to the Basecase). This clearly highlights the importance of the selection of different sourcing countries to minimise deforestation impacts.

Figure 17 Cumulative deforestation potential of the business-as-usual scenario under different deforestation allocation scenarios, 2025-2050

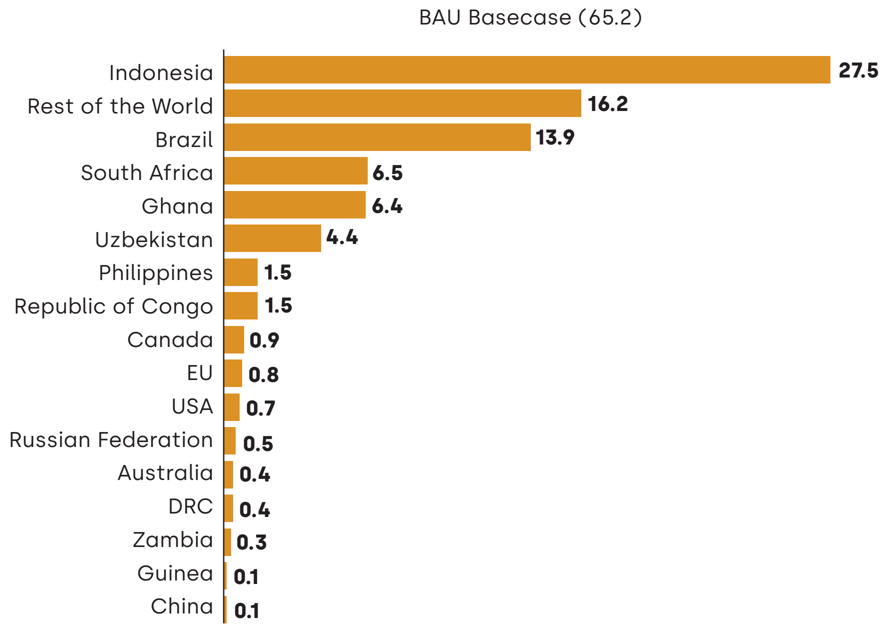


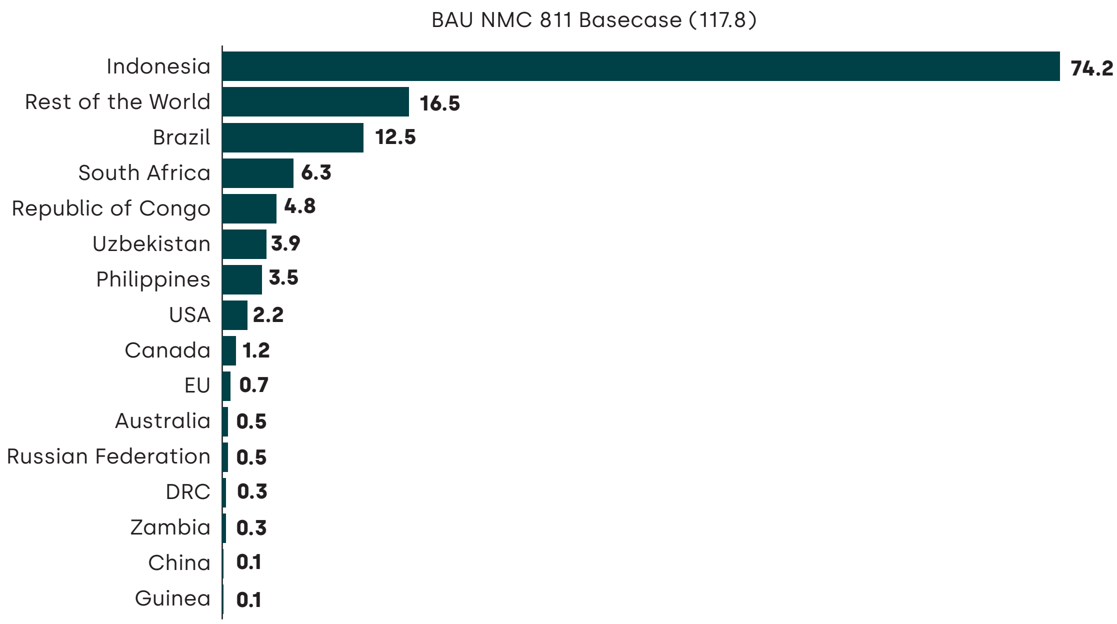
Source: own calculations, WU Vienna

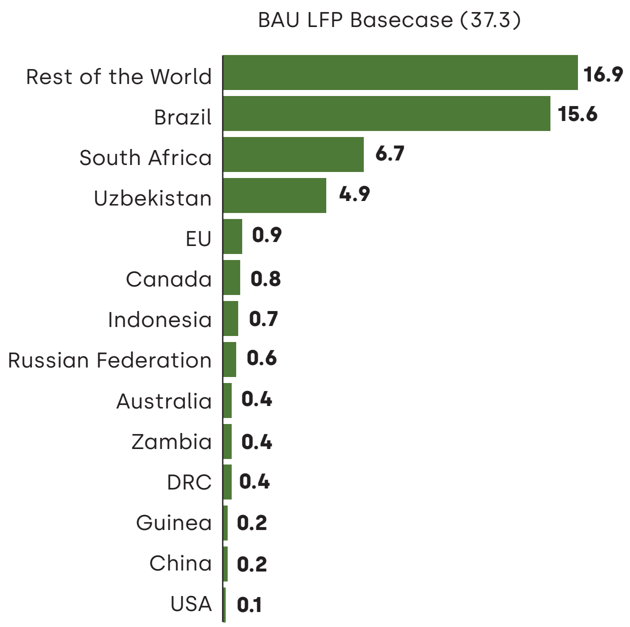
Figure 18 shows the deforestation by country in different battery technology scenarios under a BAU pathway and a Basecase country allocation. In the BAU and the NMC 811 scenarios, Indonesia clearly stands out as the hotspot for deforestation, caused particularly by nickel and cobalt mining. Brazil ranks second in both scenarios. Due to high cobalt demand in the NMC 811 variation, the DRC also appears as an important location of deforestation. Due to the absence of nickel and cobalt mining, Indonesia does not appear in the LFP variation. Brazil is the country with the highest deforestation impacts in that scenario, but forest loss is distributed across a large number of countries as observed in the large 'Rest of the World' group.

With a share of below 1%, the EU is not affected strongly in any of the three scenarios. This is due to the fact that the current share of mining within the EU as reflected in the Basecase allocation scenario is small (12% of copper, 9% of iron, and 4% of bauxite supply, see Table 6 below), while the deforestation intensities are rather low (exceptions are copper extraction in Poland and iron mining in Sweden, see Figure 15). However, as with other mining countries, future deforestation intensities in the EU might increase in cases where metal reserves with decreasing ore grades are being mined.

Figure 18 Cumulative deforestation potential in the business-as-usual scenario under different battery technology scenarios for countries (1000 hectares), 2025-2050





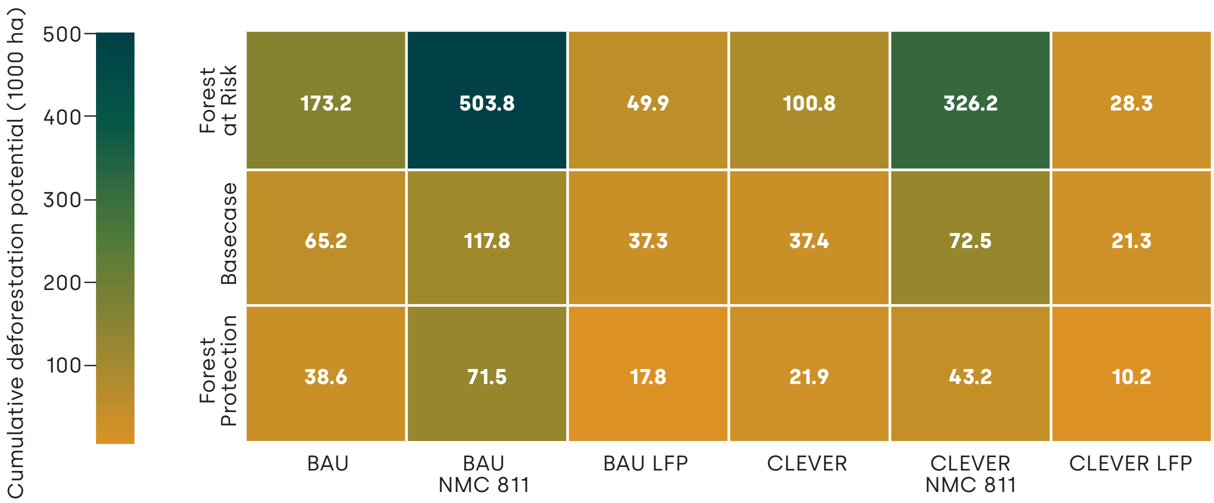


Source: own calculations, WU Vienna

4.6 POTENTIAL TO REDUCE EV-LED DEFORESTATION

Figure 19 combines all six EV mobility scenarios with the three deforestation allocation scenarios. It shows that there is a factor of 50 between the scenario with the highest and lowest deforestation implications. Focusing on the NMC 811 battery technology and sourcing from deforestation hotspot countries leads to the highest possible deforestation impacts (503.8 thousand hectares). In contrast, combining sourcing approaches that consider deforestation implications (Forest Protection scenario) with sufficiency measures (CLEVER scenario) offers the greatest potential for forest conservation with only 10.2 thousand hectares of forest loss.

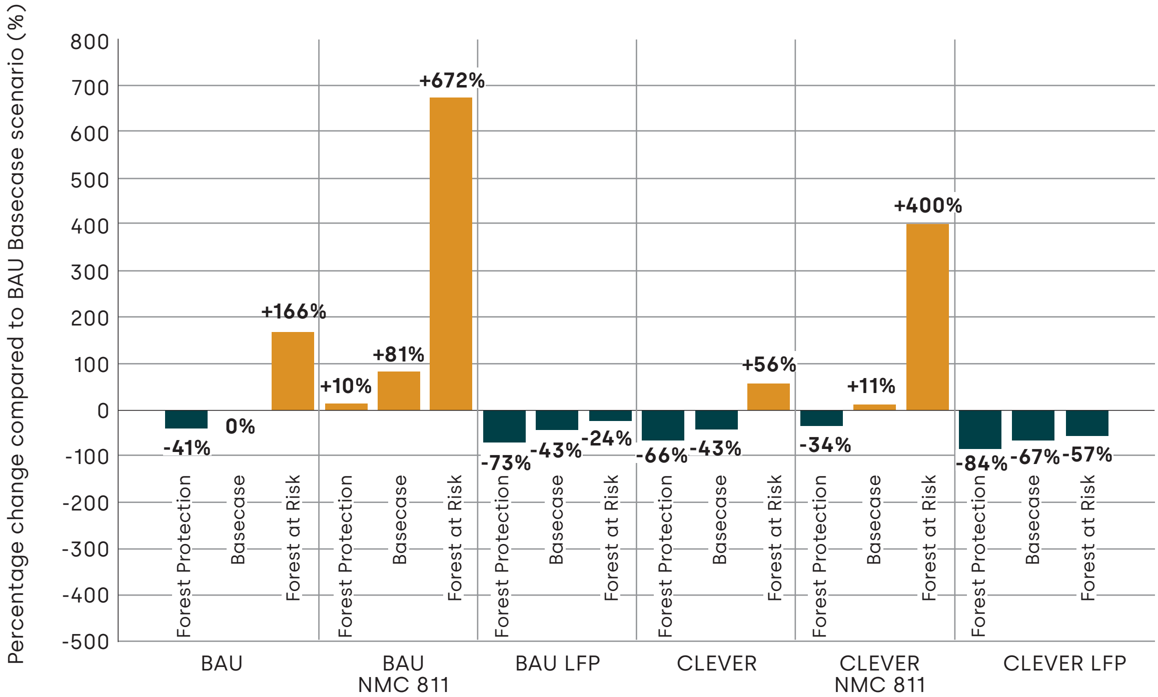
Figure 19 **Cumulative deforestation potential under different scenarios, 2025-2050**



"BAU": scenario with EVs with different battery technologies; "BAU NMC 811" scenario: scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "BAU LFP" scenario: scenario where all EVs have lithium-ion batteries with LFP cathodes; "CLEVER" scenario: mix of battery-powered vehicles, a general reduction in mobility, and a significant shift toward active transport modes and public transport; "CLEVER NMC 811" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "CLEVER LFP" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with LFP cathodes.
Source: own calculations, WU Vienna

Figure 20 illustrates the reduction potential of different scenarios compared to the BAU Basecase combination. Whereas a scenario with LFP as the dominant battery technology could reduce deforestation by -23% to -73% compared to the BAU scenario, a scenario with all EU EVs having NMC 811 batteries would increase deforestation substantially in all three sourcing scenarios. Combining a forest-responsible sourcing strategy (Forest Protection scenario) with sufficiency measures (CLEVER scenario), and a switch to LFP batteries could reduce cumulative deforestation by more than three quarters compared to the BAU Basecase. However, since material extraction also causes many other environmental impacts, a reduced material demand scenario such as CLEVER will also positively impact other environmental issues related to metal mining and processing, such as energy input, GHG emissions, water use and pollution.

Figure 20 **Reduction potential of cumulative deforestation 2025-2050 compared to business-as-usual Basecase scenario**



Business-as-usual (BAU)": scenario with EVs with different battery technologies; "BAU NMC 811" scenario: scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "BAU LFP" scenario: scenario where all EVs have lithium-ion batteries with LFP cathodes; "CLEVER" scenario: mix of battery-powered vehicles, a general reduction in mobility, and a significant shift toward active transport modes and public transport; "CLEVER NMC 811" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with NMC 811 cathodes; "CLEVER LFP" scenario: variant of the CLEVER scenario where all EVs have lithium-ion batteries with LFP cathodes.
Source: own calculations, WU Vienna

Measures promoting alternatives to passenger car mobility can lower the demand for metals required, reducing mining-related deforestation. Image: A lady riding a bike in Amsterdam, the Netherlands, by Jason Wells/Shutterstock

5. RECOMMENDATIONS

The transition to EVs is an important step in decarbonising the EU's transport sector and achieving climate neutrality by 2050.

Our results indicate that under a Business-as-usual (BAU) scenario, where mobility patterns in the EU remain unchanged, the demand for critical metals required for the EV transition by 2050 will rise significantly, driving the expansion of mining activities and related forest loss. However, the deforestation impacts estimated in this study are conservative. They do not account for indirect deforestation such as building up infrastructure for mineral processing, storage, and transport, or settlements in the surrounding areas, creating new agricultural land and pasture land with impacts on forest loss. These indirect impacts on forest loss have been shown to be particularly high in important mining countries such as Indonesia and Brazil (Giljum et al., 2022). Moreover, these results should be interpreted in the context of the EU's share of global demand. By 2050, the EU is projected to account for only around 20% of total demand (Bloomberg, 2024) meaning the overall deforestation impact of metal extraction induced by global EV demand will be substantially larger.

The comparisons of the scenarios showed that there are three main leverage points for addressing forest conservation: (1) the implementation of sufficiency measures that promote smaller and therefore more affordable cars, and alternatives to passenger car mobility in the EU (2) the selection of battery technologies that contain raw materials with lower deforestation impacts; and (3) sourcing of metals from mining countries with low deforestation intensities for the specific metals and established forest protection practices.

The recommendations formulated below focus on deforestation, as forest loss is an important proxy for a range of other environmental impacts, reducing biodiversity and other ecosystem functionalities (Faria et al., 2023). However, other environmental categories (e.g., energy use, GHG emissions, water use, water and soil pollution) also need to be considered in a broader environmental assessment framework.

5.1 IMPLEMENTING SUFFICIENCY MEASURES IN EU MOBILITY

A range of measures exist to realise sufficiency in the EU passenger transport sector. As this study shows, these measures can have a significant impact on demand for primary metals to manufacture electric vehicles and can therefore be a key angle to reduce mining-related deforestation.
It includes 1) supporting alternatives to car mobility and 2) supporting smaller cars and batteries.

5.1.1 SUPPORT ALTERNATIVES TO CARS

For EU Policymakers:

- Set a policy for sustainable mobility. This would mean reducing car dependency, enhancing public transport systems, incentivising car sharing and carpooling, strengthening sustainable transport subsidies, increasing walking and cycling infrastructure, and disincentivising car-related products and services that contribute to carbon emissions.

- Public investments should be made to expand and improve public transport systems using renewable energy such as electric buses, trains, bicycles and trams and city charging infrastructure, facilitating the transition to a shared mobility sector.

Improving public transport systems, active travel infrastructure, and shared mobility is key to reducing car-related carbon emissions in Europe. Image: Parking for carpool vehicles, by Trata 2.1/CIPRA Slovenia

Various measures should be implemented to limit car use and develop alternative transport modes. Overall, frameworks and incentives should shift to developing alternative transport modes and reducing car dependency, in addition to measures that encourage walking, cycling, car-pooling and –sharing, localised provision of services and supplies, and short-distance travel.

Policy needs to support the transition of the mobility sector away from private cars towards a public transport system running on renewable energies. The success of these alternatives will ultimately depend on user choices. **Expanding public transport infrastructure and improving the quality of public transport services** and their ease of use will therefore be decisive success factors in that transition.

Promoting car sharing and carpooling is another key area. Measures include creating a carsharing bonus financed by schemes such as the Energy Savings Certificate in France; establishing or expanding financial incentives for those giving up their old car to subscribe to a carsharing service; and mandatory setting aside of parking spaces for carsharing in places such as train stations.

Measures to disincentivise products and services that are climate harming and incompatible with a carbon-neutral pathway will also be necessary, alongside the broader shift towards alternative transport modes. This can include measures to prohibit advertisements for unaligned products and services, or penalty fees for purchasing certain vehicles, such as is currently implemented in France.

5.1.2 SUPPORT SMALLER CARS AND BATTERIES

For EU Policymakers:
- Set up a methodology and framework for an environmental score for EVs.
- Use public procurement to incentivise resource reduction and circular battery design.

For Member States: Develop a bonus-penalty scheme to **help limit battery size and/or vehicle weight.**

For cities: Implement **progressive parking fees based on vehicle weight,** following the examples of Lyon and Paris (France), which already do this for internal combustion engine (ICE) vehicles.

Limiting battery size ensures a balance between cost, affordability and environmental impact. Smaller batteries require less materials and therefore minimise environmental risks and impacts.

Various public policies at several levels, ranging from the EU to the local scale, could be enacted to reduce vehicle size and weight, and therefore battery size.

At the EU level, **the Commission** could set up a framework to foster resource, climate and energy efficiency in EVs to reduce the impact of cars beyond tailpipe emissions (T&E, 2024) and prioritise resource reduction and circular design in the procurement of products, work and services involving the battery industry.

At the **national level,** a bonus-penalty scheme could be developed to **help limit battery size** and/or vehicle weight. To improve the efficacy of this measure, we must (1) reduce the threshold for application of penalties to 1.2 tonnes, (2) establish a weight-based bonus for vehicles below the threshold, (3) extend the scope of this weight-based bonus-penalty scheme to so-called zero-emission vehicles (with a threshold for application that could exclude the weight of the battery), and (4) combine the weight-based bonus-penalty scheme with a “battery capacity” bonus-penalty scheme. As an example, France has already enacted a weight-based penalty on the purchase of new vehicles, but this penalty only applies to vehicles over 1.6 tonnes and does not apply to EVs and thus has no impact on EV or battery size. Those four measures therefore need to be implemented in addition to replicating France's current regulation.

At the **local level,** authorities could implement **progressive parking fees based on vehicle weight,** following the examples of Lyon and Paris, which already do this for ICE vehicles. For now, urban areas limit accessibility of cars but it is restricted to CO_2 emissions. Such policies should also include monitoring of the materials footprint of vehicles. The biggest impact would be at the urban level and should therefore be the responsibility of regional governments.

All these measures apply to passenger mobility since electric road freight is not yet developed (although new EU regulations include efforts to boost its development). Public policies should also be created to limit the resource consumption of trucks, including limiting their battery size.

5.2. CHOOSE LOW-DEFORESTATION BATTERY TECHNOLOGIES

This study clearly indicates that the choice of battery technology significantly impacts deforestation levels globally. Strategic decisions on future battery technology paths should be evaluated from a deforestation perspective.

Battery technology choices play a crucial role in limiting extraction and sourcing of materials and minerals from forests. More energy efficient battery technology using lower risk materials has already been developed and should be further refined. By choosing 1) recent technology that would reduce deforestation-risk, alongside 2) prioritising recycling and recycled materials, it is possible to achieve battery production with minimum impacts on forests.

5.2.1. FAVOUR LOW-DEFORESTATION BATTERY TECHNOLOGIES

For EU policymakers:

- Align the Critical Raw Materials Act mandate with circular economy goals by ensuring that a certain percentage of joint-purchases and stockpiling come from recycled materials to promote a secondary raw materials market.
- Fund research and development for next-generation batteries using abundant, low-impact materials (e.g., sodium-ion) and prioritise gigafactories producing LFP batteries over NMC batteries within the Net Zero Industry Act.
- Link public procurement to deforestation-free sourcing by mandating that all publicly funded battery contracts meet strict due diligence criteria (e.g., verified deforestation-free nickel, cobalt, graphite) and favour LFP chemistries, supported by blockchain-enabled Digital Product Passports for traceability.

For industry: Opt for low-deforestation and deforestation-free batteries and invest in innovation towards lower-deforestation battery technology.

For investors: Incorporate deforestation from mineral extraction into nature-related risk assessments for companies in battery supply chains.

To minimise deforestation impacts, **policies should prioritise battery technologies that have a lower deforestation impact compared to alternatives.** The current focus of EU policies and investment favours NMC batteries, which will potentially have significant impacts on global forest loss. Alternatives with much lower deforestation consequences, such as LFP batteries, should be explored. LFP batteries are gaining momentum in the electric car market. In 2023, 15% of all EVs sold in Europe contained LFP batteries, with projections indicating this will increase to 38% in 2025. By 2030, LFP batteries are expected to constitute more than half (57%) of EV sales, driven by the increasing focus on affordable EVs and emerging technologies like lithium manganese iron phosphate (LMFP).

Pressures on metal extraction and forest ecosystems could also be reduced by **supporting the development of other battery technologies,** notably sodium-ion batteries that operate with different materials to produce anodes and cathodes, including hard carbon and phosphates. However, as an emerging technology, challenges still remain to be solved (Qiu et al., 2024).

5.2.2 DEVELOP RECYCLING INDUSTRIES FOR BATTERIES

For EU policymakers:
- Strengthen the EU Batteries Regulation.
- Speed up recycling capacity, foster reusability and extended lifetime for batteries through the upcoming Circular Economy Act.
- Encourage efficient battery recycling and strengthen the governance of collection and recycling schemes. Improve traceability and knowledge of the future of end-of-life vehicles. Set ambitious collection targets in EU regulations for all types of batteries. Strengthen recycling facilities and infrastructure in the EU. Set targets to reduce the overall need for virgin materials from extraction.
- Increase funding for strategic recycling projects under the Critical Raw Materials Act.

For investors: Prioritizing investments in recycling, check quality of recycling technologies and choose the best options.

Another key dimension regarding battery use with important implications for deforestation outcomes is **encouraging efficient battery recycling.** Based on a Transport and Environment study (2024), Europe will be able to build a sustainable electric vehicle industry by emphasising recycling, as this addresses pressing challenges in the critical minerals space, such as resource scarcity, regional dependency and environmental impact. The Batteries Regulation distributes roles and obligations for the collection of EV batteries but lacks a concrete collection target (which would at least support the development of traceability, proper reporting systems and comprehensive studies to document EV batteries flows) and sets a 65% rate for recycling efficiency. It also includes recovery targets for lithium, nickel and cobalt that will be increased over time. There will be requirements for recycled content for new batteries starting from 2031 (to double check onwards), also to be increased over time.

There are key steps that would enable this, such as:

- Improve traceability and knowledge about the current and future flows of end-of-life vehicles (ELVs) and their batteries;
- Set ambitious and concrete collection targets and reporting mechanisms for ELVs and ELV batteries in EU regulations, as the sole generic requirements based on best-efforts obligations did not prove truly efficient so far;
- Set specific targets for recycling metals of the battery versus recovery targets (excluding downcycling-type uses);
- Strengthen targets for incorporating recycled materials, into battery manufacturing, that encourage recycling of battery-quality metals;
- Support research and development on innovative recycling technologies to obtain separate, high-quality metals;
- Establish governance systems for the collection and recycling value chain to ensure better visibility on current and future flows and activate investment capacity among recycling operators.

The upcoming Circular Economy Act creates opportunities to speed up recycling capacity, further simplify intra-EU shipment of end-of-life products and put in place quality standards for secondary materials to ease scaling and investment.

5.3 RESPONSIBLE SOURCING AND STRENGTHENING LEGAL FRAMEWORKS

The comparison of different sourcing scenarios in this report shows how sourcing strategies significantly influence overall deforestation.

- Policy and legal frameworks must be crafted to ensure a robust framework for responsible sourcing, while actors along the supply chain must shift to responsible sourcing and commercial practices.
- Third party standards and assurance systems are important tools used by downstream and upstream companies to evaluate the risks and impacts of their sourcing practices and mining operations to individual mining sites, smelters, refiners or manufacturing plants in their supply chains. However, current standards have several shortcomings. Robust standards are necessary to address environmental protection, human rights and labour standards. Mining standards can act as tools to enable and promote accountability and transparency, traceability, addressing Indigenous Peoples and local communities' rights by using multi-stakeholder engagements.
- Finally, establishing No-go zones in mining is crucial for environmental protection, the rights of Indigenous Peoples and Local Communities, and sustainable resource management.

5.3.1 STRENGTHEN AND RESPECT LEGAL FRAMEWORKS FOR RESPONSIBLE SOURCING

For EU Policymakers:
- Uphold corporate accountability legislation including the Corporate Sustainability Due Diligence Directive (CSDDD), the Corporate Sustainability Reporting Directive (CSRD) and the Taxonomy Regulation.
- Ensure the full entry into force of the due diligence obligations of the EU Batteries Regulation, no later than August 2025, to ensure a world-leading EU battery supply chain and a commitment to clean and ethical batteries.
- Establish robust criteria for due diligence schemes, as foreseen under the Batteries Regulation, in consultation with stakeholders and rightsholders.
- Incentivise responsible sourcing through innovative trade and investment agreements aligned with sustainable development, good governance, and human and environmental rights.

For upstream and downstream companies:
- Adopt time-bound policies and commitments that take a clear stance on avoiding and eliminating deforestation in mineral supply chains.
- Set and implement strong policies on the rights of Indigenous Peoples and Local Communities, including a commitment to Free, Prior and Informed Consent (FPIC). Develop independent and transparent grievance mechanisms.
- Select the most robust standards and conduct regular, independent third-party audits and time-bound commitments to progressively improve performance, ensuring inclusion of rightsholders and affected parties.

For downstream companies:
Develop and implement a robust due diligence system. Publicly disclose suppliers and report on progress towards deforestation and human rights targets.

For investors:
- Demand that companies use a robust due diligence system, actively prevent, mitigate and remedy social and environmental impact in their supply chains, and develop investment criteria that incentivise adoption of robust standards.
- Actively engage with portfolio companies to ensure best social and environmental practices are implemented in mineral supply chains.
- Adopt company expectations that take a clear stance on avoiding and reducing, and with the ambition of eliminating, deforestation linked to extractive assets.
- Adopt company expectations to respect and implement FPIC for Indigenous Peoples and local communities, including the right to withhold consent.

To mitigate the environmental and social impacts of mining in forest-rich areas, it is key to **implement and strengthen environmental regulations** and **systematically monitor ecological and social consequences of mining operations.** These measures are relevant for both producing and purchasing countries, as well as international trade agreements and negotiations or guidelines such as those of the Organisation for Economic Cooperation and Development (OECD)'s. It is pivotal to integrate environmental considerations into mine planning and decision-making. The **Mitigation Hierarchy Framework, coupled with sufficient measures,** is a useful tool to prioritise avoidance, minimisation, restoration, and offsetting of impacts to safeguard biodiversity. Additionally, it is important to **expand the application of the Mitigation Hierarchy to address indirect and cumulative effects,** particularly in regions where increasing demand for minerals drives rapid infrastructure and industrial development (Sonter et al., 2023).

5.3.2 IMPROVE MINING STANDARDS AND THIRD-PARTY AUDITS

For standard setters and assurance schemes:

- Align standard requirements with best international human rights and environmental standards and expectations.
- For biodiversity, introduce standard requirements and criteria that include the avoidance of natural habitats and other critical habitats, aligned with the International Finance Corporation (IFC) Performance Standard 6.
- Include FPIC as an assessment criterion across standards, and as a minimum criterion for validation and accreditation.
- Ensure auditing and accreditation processes are rigorous, independent and transparent, with adequate requirements for participation from and consultation with local communities, and other key stakeholders.
- Ensure credible standard setting and implementation through systems of multi-stakeholder governance as well as increased transparency and disclosure.

Currently, there are at least eight accreditation schemes: Initiative for Responsible Mining Assurance (IRMA), Responsible Minerals Initiative (RMI), International Council on Mining & Metals (ICMM), Towards Sustainable Mining (TSM), Responsible Steel, Global Steel Climate Council (GSCC), Aluminium Stewardship Initiative (ASI), and Copper Mark. IRMA is the most comprehensive standard.

The recent release of the ICMM's Consolidated Mining Standard Initiative (CMSI) has raised concerns within civil society which feels it will drive the mining industry to a race to the bottom at the expense of communities (Business & Human Rights Resource Centre, 2024). It has weak indicators related to multi-stakeholder processes, especially for deforestation, and the rights of Indigenous Peoples and local communities. The CMSI poses significant risks for automakers and other downstream purchasers, especially related to addressing potential human rights abuses or environmental harm (Public Citizens, 2024). Their analysis showed significant gaps that could have harmful consequences for affected communities, downstream purchasers like automakers, and the broader mining sector. Further, the standard falls short of supporting due diligence efforts, potentially exposing companies to legal and reputational risks.

Based on several assessments by Lead the Charge, Rainforest Foundation Norway and Mighty Earth in 2024, there are still several shortcomings in mining standards. There is **urgent need to strengthen multi-stakeholder governance, credible audits and accreditation, transparency of audit findings, corrective action plans, effective grievance mechanism, compliance with ISEAL standards, and credible and comprehensive standard criteria.** All available mining standards, third party assurance and accreditation systems must be improved to fulfill their potential of driving meaningful improvements in company practice.

Regarding nature, biodiversity and deforestation, none of the mining standards include indicators with explicit language to identify potential and actual impact on natural forests, land use change and/or deforestation (Mighty Earth and Rainforest Foundation Norway, 2024). In most cases there is little guidance on which indicators or methods should be used to achieve compliance with the mitigation hierarchy. This leads to insufficient due diligence when mining operations take place in forests, and a lack of standardised Means of Verification. These inconsistencies need to be addressed. Hence, pressure to strengthen these standards, to close the gaps and address the shortcomings is important.

5.3.3 ESTABLISHING ‘NO-GO’ ZONES FOR MINING

For EU Policymakers: Establish no-go zones for mining in Europe and promote multilateral discussions on definitions and enforcement.

For the industry: Commit and implement ‘no-go' zones for mining in company policy sourcing, and set binding compliance criteria for suppliers.

For investors: Refrain from financing mining in ‘no-go’ zones, and incorporate ‘no-go’ zones for mining into relevant policy documents at the portfolio level.

To protect important areas of nature and biodiversity, it is necessary to establish ‘no-go’ zones for mining, but neither the international legal framework, nor the EU one include them. **Mining should be entirely prohibited in primary forests, in protected areas and ecologically sensitive biomes** such as peatlands, grassland, and mangrove ecosystems particularly in regions containing extensive deposits such as laterites (a red soil, typical in tropical countries), where extraction leads to large-scale land use changes, posing significant risks to biodiversity. This is also why robust planning and sufficiency measures are needed to enable us to effectively assess the amount of these minerals needed. Sufficiency should always prevail over corporate interests.

No-go zones should include:

1. **Protected Areas, including** Indigenous Protected Areas (IPAs) and community conservation and protected areas (ICCAs), World Heritage Areas, RAMSAR sites, UNESCO Global Geoparks and Biosphere Reserves, IUCN Protected Areas.
2. **High Conservation Value (HCV) Areas** including key biodiversity areas, and Intact Forest Landscapes.
3. **High Carbon Stock (HCS) Areas,** including primary forests and peatlands.
4. **Significant Natural Ecosystems,** including the deep sea and small islands.
5. **Critical Water Bodies.**
6. **Indigenous Peoples and local communities’** land that does not have their FPIC for prospecting or mining.

In Indonesia, cobalt and nickel production is on the rise, driven by government policies aiming to integrate the country into the global EV supply chain. Image: An open pit nickel mine on Manoram Island, Indonesia, by Forest Watch Indonesia.

6. METHODOLOGY AND DATA

The methodological framework used for the calculation of potential future deforestation for EU EV demand follows three steps:

- First, we calculated the future metal demand for EVs in the EU using four different scenarios (see section 6.1).
- Then, based on our own calculations and existing literature on the automotive sector's global supply chains, we developed three different scenarios for the origin of raw materials by mining countries (see section 6.2).
- Finally, we converted primary metal demand into crude ore, allocated it to different supplying countries and combined it with deforestation coefficients to assess deforestation associated with metal demand (see section 6.3).

6.1 ASSESSING FUTURE MATERIAL DEMAND FOR EUROPE'S EVS

6.1.1 THE BAMASI MODEL

The BAMASI tool, developed by the Association négaWatt, allows quantifying the metals required for road transport in different mobility and energy transition scenarios. For this scenario metal demand was analysed for iron, aluminium, copper, manganese, nickel, cobalt, lithium, and neodymium.

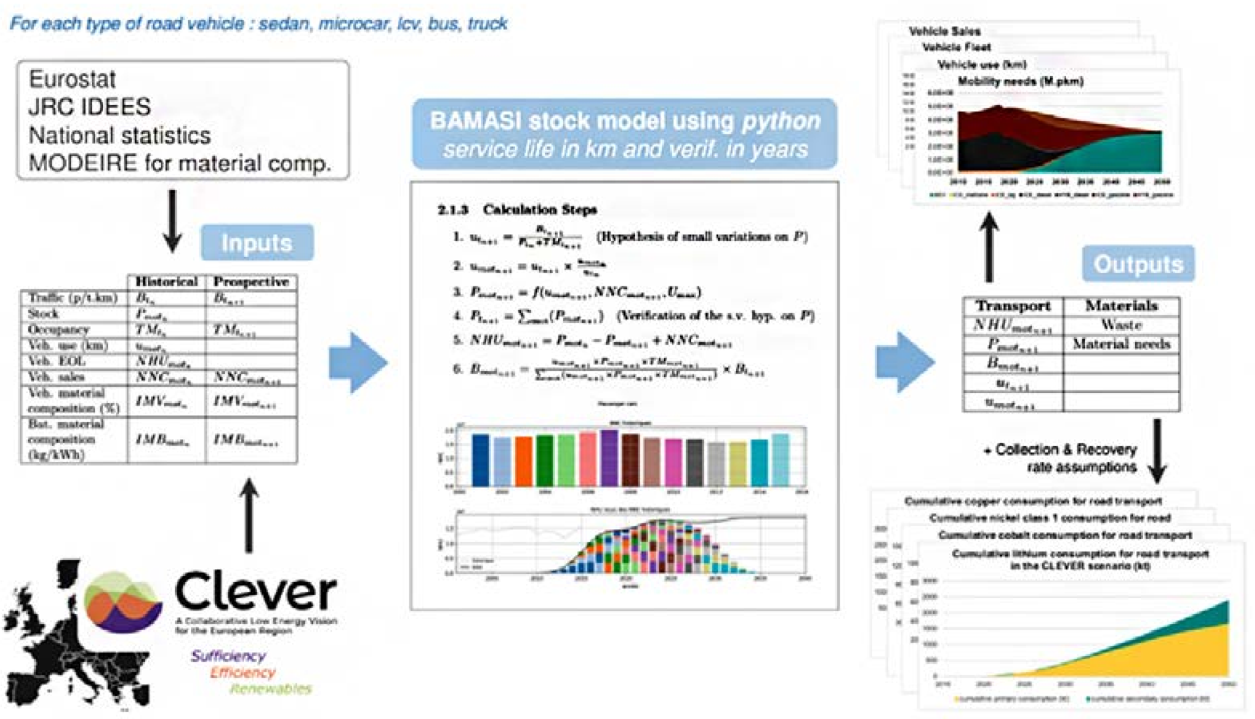
BAMASI is a stock model that explicitly considers the role of in-use stocks (metals present in vehicles in use) in past, present, and future material use.

This tool is used to model material requirements based on mobility needs. The input parameters shown in Table 1 enable us to model tomorrow's travel needs, which will be met by personal vehicles. This foresight tool makes it possible to imagine realistic but "controllable" trajectories. Indeed, unlike other models, the tool makes it possible to imagine proactive policies, for example in terms of car-sharing or better design of home-work journeys (increasing vehicle occupancy rates), and to see their effects on materials consumption. The effects of changes in raw material prices over time, which are extremely difficult to predict, such as the rapid substitution of one technology for another, or supply disruptions linked to the geopolitical context, are not taken into account in this model, which is essentially based on needs, and proposes an evolution of the battery technology mix based on current knowledge of these technologies and their availability on the market.

In the tool, a vehicle's lifetime is defined in kilometres (e.g. 195,000 km for a passenger car) rather than years. This is intended to reflect the sufficiency assumptions in the mobility sectors, which lead to a reduction in the annual distance travelled by vehicles and in the vehicles sales.

Figure 21 illustrates the structure of the BAMASI model, and Table 1 and Table 2 illustrate its input and output parameters.

Figure 21 **Structure of the BAMASI Model**



Source: own illustration, Association négaWatt

Table 1 **Input parameters for the BAMASI Model**

	Historical	Prospective
Traffic	Vehicle traffic defined as mobility needs. It is the average distance travelled per capita, i.e. average number of kilometres travelled per person within the EU for the year n	Vehicle traffic is here defined as mobility needs in year n+1
Stock	Vehicle stock for a specific motorisation, year n	
Occupancy	Occupancy rate define as persons per vehicle, year n	Occupancy rate define as persons per vehicle, year n+1
Vehicle use (km)	Vehicle use for a specific motorisation, year n	
Vehicle EOL	End-of-life (EOL) vehicles for a specific motorisation, year n	
Vehicle sales	Total vehicle sales, year n	Total vehicle sales, year n + 1
Vehicle material composition (%)	Vehicle material composition for a specific motorisation (%), year n	Vehicle material composition for a specific motorisation (%), year n+1
Battery material composition (kg/kWh)	Battery material composition for a specific motorisation (%), year n	Battery material composition for a specific motorisation (%), year n+1

Source: Association négaWatt

Table 2 **Output parameters for the BAMASI Model**

Transport	Materials
End-of-life (EOL) vehicles for a specific motorisation, year n+1	EOL vehicles material content
Vehicle stock for a specific motorisation, year n+1	Material requirements
Vehicle traffic for a specific motorisation, year n+1	
Vehicle use corresponding to the yearly kilometres travelled by the vehicle, year n+1	
Vehicle use for a specific motorisation, year n+1	

Source: Association négaWatt

6.1.2 DATA

The BAMASI model is based on different datasets on historical vehicle stock, new sales and end-of-life vehicles. For the years 1990 to 2015, the JRC IDEES 2015 database is used, for the period 2016 to 2019, the “New Mobility Patterns” database by EUROSTAT. In cases where data for individual countries was absent, data was extrapolated based on GDP per capita values. To calculate future material demand induced by the EU transitioning from combustion engines to EVs in 2050, a set of scenarios following different assumptions was developed.

6.1.3 SCENARIOS AND ASSUMPTIONS

This study examines six scenarios for the EU’s future material demand: a reference business-as-usual (BAU) scenario, two variations of the reference scenario featuring different dominant battery technologies ("BAU LFP battery" and "BAU NMC811 battery"), and a sufficiency-focused scenario ("CLEVER"), and two variations of the reference scenario featuring different dominant battery technologies ("CLEVER LFP battery" and "CLEVER NMC 811 battery"). All scenarios are aligned with current EU policies aimed at decarbonizing the mobility sector by 2050 and the ban on sale of new petrol and diesel cars from 2035. Table 3 provides an overview of these four scenarios and their distinct assumptions.

Table 3 Main assumptions for transport and battery capacity in the business-as-usual and CLEVER-scenario, and the two variants

	2018	2050					
Indicator	**Historic**	**BAU**	**BAU LFP battery**	**BAU NMC 811 battery**	**CLEVER**	**CLEVER LFP battery**	**CLEVER NMC 811 battery**
Average occupancy rate	1.63 person per vehicle	1.63 person per vehicle (100%)*	1.63 person per vehicle (100%)*	1.63 person per vehicle (100%)*	1.98 person per vehicle (121%)*	1.98 person per vehicle (121%)*	1.98 person per vehicle (121%)*
Mobility needs	4,254 billion km	5,076 billion km (119%)*	5,076 billion km (119%)*	5,076 billion km (119%)*	3,105 billion km (73%)*	3,105 billion km (73%)*	3,105 billion km (73%)*
Share of microcars	0%	0%	0%	0%	20%	20%	20%
Battery capacity conventional passenger car	50 kWh	75 kWh	75 kWh	75 kWh	60 kWh	60 kWh	60 kWh
Battery capacity microcar	7 kWh	15 kWh	15 kWh	15 kWh	10 kWh	10 kWh	10 kWh
Battery technology		Mix reflecting industry trends	LFP only	NMC 811 only	Mix reflecting industry trends	LFP only	NMC 811 only

* Index 2018 = 100%

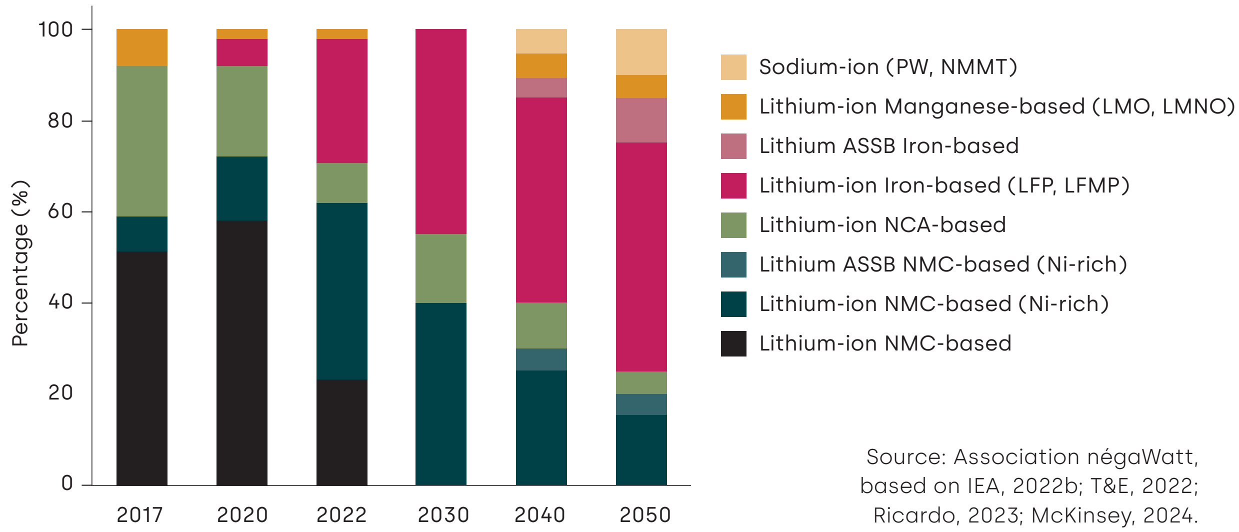
Source: Association négaWatt

6.1.4 BATTERY TECHNOLOGY

In both the business-as-usual and CLEVER scenarios, assumptions about battery technology development represent current industry trends and are own projections based on literature (IEA, 2022b; T&E, 2022; Ricardo, 2023; McKinsey, 2024). Figure 24 shows the technology mix and its evolution considered in the reference scenario and the CLEVER scenario from 2017 to 2050.

Assumptions about battery capacity of conventional cars and microcars differ in the business-as-usual and CLEVER scenarios (see Table 3).

Figure 22 **Evolution of the EU battery technology mixes considered in the BAU scenario and the CLEVER scenario, 2017-2050**



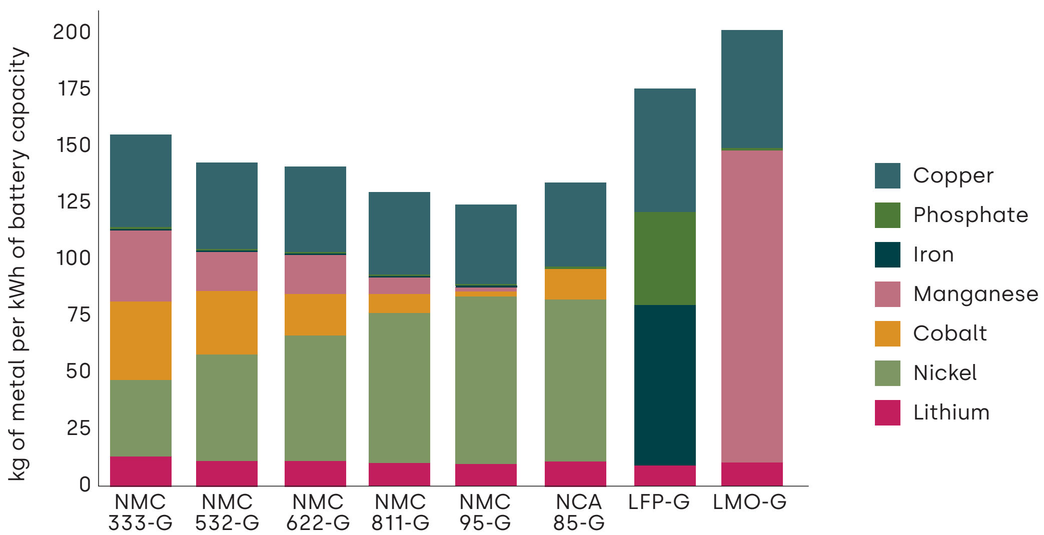
Source: Association négaWatt, based on IEA, 2022b; T&E, 2022; Ricardo, 2023; McKinsey, 2024.

The "NMC 811 battery" scenario assumes that, starting in 2025, all new EV sales in the EU will utilize NMC 811 technology. This choice reflects the widespread use of lithium-ion batteries with NMC cathodes in European EV passenger cars today (Ricardo, 2023).

By contrast, in Asian EV passenger cars, lithium-ion batteries with LFP cathodes are more commonly used. To assess the environmental impacts of different battery technologies, the alternative "LFP battery" scenario assumes that, from 2025 onward, all new EU EV sales will rely on lithium-ion batteries with LFP cathodes.

To translate these mixes of battery technologies into material requirements (Figure 23), the metal composition of the batteries was calculated with the BAMASI model with data on metal requirements of different battery technologies based on Argonne National Laboratory's Battery Performance and Cost (BatPaC) Model v5.1 (Knehr, 2022).

Figure 23 **Metal requirements of different battery technologies**



Source: Association négaWatt, based on Argonne National Laboratory's Battery Performance and Cost (BatPaC) Model v5.1 (Knehr, 2022)

6.1.5 RECYCLING

The assumptions taken into account for the evolution of the recycling of metals used in the automotive sector focus on batteries. Indeed, in the coming years, the management of end-of-life vehicles will have to evolve considerably to cope with the electrification of the fleet, and the recommendations for the management of batteries seemed to us to be a major issue for the future of vehicle recycling.

The EU introduced a regulation concerning batteries and waste batteries in 2023 (European Parliament and European Council, 2023b) aiming for recovery rates of 50% by 2027 and 80% by 2031 for critical materials such as lithium, cobalt, and nickel (see Table 4). All scenarios are based on these EU targets, but with a significant difference that makes our assumptions more ambitious: our targets are recycling rates not recovery rates. Targets expressed in terms of recovery rates allow for use of metals in downcycling applications such as the use of slag remaining after the recovery of certain metals from blackmass (a product resulting from the recycling of batteries in pyrometallurgy) in road foundations. This current use leads to the loss of lithium, for example, in applications where none of its specific properties are exploited. Considering recovery rates as recycling targets is equivalent to estimating that there is no downcycling in this percentage.

To achieve ambitious recycling rates for battery metals, it is assumed that all end-of-life batteries are collected and reused within the automotive sector. Although these assumptions differ from current industrial practices, they are technically and strategically feasible and based on the notion that recycling industries are developed in Europe.

Table 4 Yearly recycling rate assumptions (depending on stock) for the metals used for the battery cathode

	2018	2027	2031	2050
Cobalt	0%	90%	95%	95%
Lithium	0%	50%	80%	80%
Manganese	0%	90%	95%	95%
Nickel	0%	90%	95%	95%

Source: Association négaWatt

Regarding the metals used in the EV outside of the battery cathode, all four scenarios follow a simplified and conservative approach, applying historical trends for future recycled content. Table 5 summarizes assumptions on the use of recycled content for metals outside of the battery cathode.

This does not represent very ambitious recycling assumptions for industrial metals. Indeed, for steel and aluminum - that are already mostly recycled in the end-of-life vehicle sector - the levers for increasing the share of recycled aluminum and steel in global production do not appear to lie in improving the management of end-of-life (EOL) vehicles. The only assumptions that are lacking in our study are those concerning the increase in the proportion of recycled content for copper and nickel, but they would have required a forecast for many other sectors, which has not been carried out here.

It should be noted, however, that comprehensive recommendations for improving recycling in the European automotive sector should include (in addition to the specific recommendations on batteries developed in the recommendations section):

- general recommendations to limit leakage to illegal channels and exports of material in EOL vehicles;
- improved sorting and collection of copper in the short term;
- and in the medium term, specific recommendations to facilitate the dismantling and recycling of electric motors, whether they have permanent magnets or copper coils.

Table 5 **Recycled content assumptions for the metals used outside of the battery cathode**

	2018	2050
Aluminum	50%	50%
Copper	25%	25%
Stainless steel	60%	60%
Steel	60%	60%
Neodymium	0%	0%
Nickel (excluding the battery cathode)	25%	25%

Source: Association négaWatt

6.1.6 SUFFICIENCY

Unlike the BAU scenario and its two variants ("LFP battery" and "NMC811 battery"), the CLEVER scenario focuses on sufficiency and is based on different assumptions about mobility trends and battery capacities (see Table 3).

The CLEVER scenario, published in June 2023, models the evolution of the industrial, residential, mobility, agricultural, forestry, land-use and bioenergy sectors for the EU. It is a pre-existing scenario that is broader than the issue of mobility (see box below).

How the CLEVER scenario was built

The CLEVER (Collaborative Low Energy Vision in the European Region) scenario was developed by the Association négaWatt in collaboration with its network of 26 European partner associations. Based on national trajectories (bottom-up approach), it assesses all decarbonization potentials through the analysis of the energy demand reduction (sufficiency and efficiency) and the renewable energy development. It targets (i) carbon neutrality, (ii) a 100%-renewable energy mix (both as soon as possible and by 2050 at the latest) and (iii) to be in line with 1.5 degrees pathways.

The CLEVER approach introduces the concept of "convergence corridors": for each major indicator of the scenario, a corridor is to be achieved for each national trajectory by 2050. A lower bound is defined based on "Decent Living" studies and an upper bound is defined as a level of services compatible with a 1.5°C increase. This approach follows Kate Raworth's doughnut economy principle (Raworth, 2017). The sufficiency corridors for the demand-side modelling in the mobility sector are presented in the sectoral note on mobility (Toledo et al., 2023).

6.2 ALLOCATION OF FUTURE MINERAL SUPPLY TO MINING COUNTRIES

To assess the future deforestation impacts of Europe's EV demand in 2050, it is necessary to allocate the demand for different raw materials to different mining countries. Ideally, this would be based on detailed information on metal supply chains specific to EVs sold in Europe. However, such data is currently unavailable in the literature.

Moreover, the global distribution of future metal extraction associated with EV demand depends on numerous variables, including geological, economic, technological, and political factors. For example, battery production often occurs near major demand centres, with significant production capacities located in China, Europe, and the United States. International partnerships also play a crucial role in shaping the global EV supply chain. For instance, the South Korean company LG Energy Solution plans to establish joint ventures or long-term supply agreements to produce lithium iron phosphate (LFP) batteries for the European market. A partnership already exists with the French Renault Group. To supply production sites for the European market with raw materials, LG is planning partnerships with Chinese firms (Reuters 2024).

To address the range of uncertainties, we have developed three supply structure scenarios using different types of information: global mining production data, supply chain data for the average vehicle sector, and qualitative EV supply chain information.

6.2.1 BASECASE SCENARIO

In the Basecase scenario, we combine two datasets: Chinese import data derived from UN Comtrade (2024) and supply structure data for cars sold in the EU based on the GLORIA trade model (Lenzen et al., 2021) using 2022 data.

The established approach in the EV supply chain literature (Olivetti et al., 2017; Sun et al., 2019; Matos et al., 2022; Rajaeifar et al., 2022; Jones et al., 2023) is to assume that the metal supply structure for Europe's EV demand follows the general global production structure of EV-relevant metals. This means that the geographical origin of metals for the EU's EV demand is equal to the mining countries' shares in total global extraction of metals. While this approach builds upon high-quality, publicly available datasets, it assumes that all mining countries are equally involved in the EU's EV supply chain.

However, metal extraction and processing for EV production are heavily concentrated in just a few countries. This is partly due to geopolitical factors and partly because certain metals used in EV production, such as nickel, must meet specific quality requirements that are not available from all mining sites (WEF, 2019; IEA, 2023). For example, a specific type of nickel, which is essential for EV production, is only found in certain mining regions (Saegert et al., 2022). Therefore, we incorporate additional information in the base case scenario.

Firstly, we consider that EVs and internal combustion engine vehicles (ICE) share a considerable part of their material composition. Especially bulk materials such as aluminium/bauxite, copper, and iron/steel are used in both vehicle types in similar dimensions (Betz et al., 2021; IEA, 2022b). Therefore, we assume that the supply chain structure for these bulk materials for EVs is similar to the one for ICEs. We use the GLORIA model to derive this current supply structure of bauxite, copper, and iron for vehicles of different types sold in Europe.

Secondly, we consider that the value chain of EVs shows a strong concentration in China in the midstream sectors (IEA, 2022a). While for the material processing of lithium, nickel, cobalt and graphite, the market shares are between 30% (nickel) and 70% (graphite), for the production of cell components and battery cells, it is between 70% and 80%. For critical minerals such as lithium, nickel, cobalt, and manganese we can therefore assume that the Chinese import structure better resembles the EV supply chain structure than the average global mining production structure. Using UN Comtrade data, we can obtain the Chinese import structure of these raw materials.

For our basecase, we assume that the supply structure is static over time. To account for potential shifts in the supply structure and to grasp their impact on deforestation levels, we construct two alternative scenarios that reflect a shift towards supplier countries with a particularly high/low level of deforestation.

The percentage values shown in the tables below refer to the respective static distribution from 2035 onwards.

6.2.2 FOREST AT RISK SCENARIO

This scenario builds on the Basecase scenario but we assume that countries with a particularly high level of deforestation in the time period of 2000 to 2019 will increase their share. To identify deforestation intense countries, we rely on deforestation quotients derived from the methodology described in the next sub-chapter. We assume a linear change from 2024 to 2035 after which the distribution stays static until 2050.

Some developments can be expected based on currently publicly available information. The strong increase of Indonesia in cobalt and nickel production is actively supported by a governmental policy that aims to integrate Indonesia into the global EV supply chain (Huber, 2022; Szurlies and Vasters, 2024). The increase of Russia and Indonesia in copper production is in line with expected increases of their production (IEA, 2024a).

All assumptions were cross-checked with data on available reserves as reported by the US Geological Survey.

6.2.3 FOREST PROTECTION SCENARIO

This scenario also builds on the Basecase scenario, but we assume that countries with a particularly low level of historic deforestation will increase their share. To identify low-intensity deforestation countries, we again rely on deforestation quotients (see section 6.3). We assume a linear change from 2024 to 2035 after which the distribution stays static until 2050. While Australia currently only has a marginal role in the production of cobalt, it hosts 22% of global reserves which allows for potential strong increases (IEA, 2022a).

Also in the forest protection scenario, assumptions were checked against reserves as reported by USGS.

The following tables illustrate the shares of various countries providing the different raw materials in 2050. The Basecase reflects the current estimated supply structure and is assumed to stay constant until 2050. Changes in the Forest at Risk and Forest Protection scenarios progress from the current structure to the indicated structure until 2035 and then stay constant until 2050.

Table 6 Distribution of metal supply for EU EVs in different sourcing scenarios

Bauxite	Basecase	Forest at risk	Forest protection
Guinea	46%	25%	60%
Australia	13%	40%	5%
India	8%	5%	15%
China	7%	5%	15%
Brazil	6%	15%	5%
Russia	6%	10%	
EU	4%		
Sierra Leone	3%		
Saudi Arabia	2%		
Jamaica	2%		
Bosnia Herzegovina	1%		
Indonesia	1%		
Rest	1%		

Cobalt	Basecase	Forest at risk	Forest protection
DRC	78%	25%	60%
Indonesia	6%	60%	2.5%
Malaysia	5%	5%	2.5%
Philippines	3%	10%	10%
Canada	2%		
USA	2%		
Australia	1%		25%
Rest	4%		

Copper	Basecase	Forest at risk	Forest protection
Chile	24%	20%	40%
EU	12%	15%	5%
USA	9%	5%	20%
Peru	9%	5%	20%
Brazil	7%	20%	5%
Canada	5%	0%	5%
Serbia	5%	10%	5%
China	4%		
Zambia	4%	5%	
DRC	3%	10%	
Kazakhstan	3%		
Iran	3%		
Uzbekistan	2%		
Russia	2%	10%	
Mexico	2%		
Indonesia	1%		
Armenia	1%		
Rest	4%		

Iron	Basecase	Forest at risk	Forest protection
Brazil	17%	15%	10%
Russia	12%	25%	10%
Australia	11%	10%	25%
EU	9%	15%	10%
Ukraine	9%	5%	15%
China	9%	5%	5%
Canada	8%	15%	5%
India	6%	5%	15%
South Africa	5%	5%	5%
Turkey	3%		
Mauritania	2%		
Kazakhstan	2%		
Rest	5%		

Manganese	Basecase	Forest at risk	Forest protection
South Africa	43%	20%	60%
Gabon	18%	35%	10%
Australia	16%	30%	10%
China	15%	5%	20%
Brazil	3%	10%	
Côte d'Ivoire	2%		
Rest	1%		
Malaysia	1%		
Ghana	1%		
Rest	1%		

Nickel	Basecase	Forest at risk	Forest protection
Indonesia	52%	75%	30%
Philippines	39%	20%	60%
Canada	5%	5%	10%
Côte d'Ivoire	2%		
Rest	2%		

Source: WU Vienna

6.3 ASSESSING DEFORESTATION ASSOCIATED WITH EVS' MATERIAL EXTRACTION

6.3.1 HISTORIC DEFORESTATION

The assessments of future deforestation are based on historic patterns observed between 2000 and 2020. Mining-related forest loss was calculated by integrating the global forest change dataset (Hansen et al., 2013) with mine site data from three sources: Maus et al. (2022), Tang and Werner (2023), and OpenStreetMap. These datasets delineate mine extents through satellite image interpretation, resulting in a comprehensive dataset comprising 217,201 polygons covering 150,643 km^2.

Deforestation within mining sites was attributed directly to mining activities. Hansen et al. (2013) provides annual tree cover loss data at a 30-meter resolution, defining forests as areas with vegetation exceeding 5 meters in height. "Forest cover loss" refers to stand-replacement disturbances or transitions from forested to non-forested states. For this study, tree cover loss in pixels with at least 25% tree cover in the year 2000 is used as a proxy for deforestation.

6.3.2 THE DEFORESTATION MODEL

To calculate deforestation intensities by material and country, we first identified the materials associated with each polygon. This was achieved using spatial clustering based on geographical proximity, linking polygons to mine properties reported in three datasets: Jasansky et al. (2023), the S&P Database (SNL, 2024), and Global Energy Monitor (globalenergymonitor.org). This step enabled us to estimate the direct land use and deforestation attributable to each material, which was then aggregated at the country level.

A single polygon can be linked to multiple materials for two reasons: (1) by-products often reported within a single property, and (2) spatial clustering linking multiple properties to a single polygon due to close proximity. These can lead to multiple counts of the same deforested area. To address this, we rescaled country-level deforestation to the total deforestation attributed to mining activities in each country excluding multiple counts. For that, we first calculated the percentage of deforestation associated with each material across multiple countries and multiplied it by the total deforestation due to mining in that country, eliminating multiple counts. The rescaled deforestation values were then divided by the crude ore extracted in each country, as reported in the UNEP IRP Dataset (UNEP IRP, 2024). This provided the deforestation intensity per unit of crude ore extracted while preserving the relative deforestation proportions across different commodities.

6.4 LIMITATIONS

6.4.1 NO COMPARISON WITH PETROL CARS

The current study did not aim at comparing the deforestation implications between petrol cars and EVs. Petrol cars were still assumed to be part of EU's overall vehicle fleet, but no separate calculations for petrol cars were performed. It is therefore not possible to derive conclusions on the impacts of petrol cars' material demand on forest loss.

6.4.2 BATTERY TECHNOLOGY DEVELOPMENTS

Assumptions on the future battery technology mix try to propose the most realistic development based on literature and current industry trends. However, the battery sector is a fast-moving technological field and is therefore open to different interpretations and any forecasting exercise is by definition uncertain.

6.4.3 MINING DATA

Although the mining site dataset covers mines globally, it does not encompass all mining activities worldwide. Artisanal and small-scale mining (ASM) is only partially represented, as evaluating ASM as a driver of deforestation on a global scale poses significant challenges. There is no comprehensive database to consistently map ASM locations and their spatial extent. Additionally, ASM activities are highly dynamic, frequently expanding or relocating. Abandoned ASM sites are particularly difficult to identify due to their characteristic mix of bare ground, water pools, and residual or regrowing vegetation (Giljum et al., 2022). This implies that we might have omitted some mining sites that produce EV-relevant materials along with their deforestation.

6.4.4 DEFORESTATION MODEL

The model to calculate deforestation intensities is based on historical data for the period of 2000 to 2020. This implies that very recent expansions of specific mining activities are not or not well reflected in the data set. For example, Indonesia only recently started to expand its production of cobalt. The cobalt deforestation factor of Indonesia, which has a high impact on the overall result, is therefore based on data for only a few years, increasing the uncertainty around resulting deforestation.

Further, future changes in deforestation intensities were not taken into account. Intensities might increase in cases where a country opens up new mines in forested regions, or when new technologies are developed that allow turning low-grade resources into economical deposits. Intensities might also decrease, if future production is served by exploiting existing mining extents rather than mining expansion.

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